AR-009-993

DEPARTMENT OF DEFENCE

ROYAL AUSTRALIAN AIR FORCE

AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

FORMAL REPORT - TASK 0301

AS350BA SQUIRREL HYDRAULICS OUT EVALUATION

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TASK ORIGINATOR: HQ AVN SPT GP

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993

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SUMMARY

Following an aircraft accident involving A22-004 during a simulated hydraulics malfunction approach and landing on 10 Mar 97, Officer Commanding the Aircraft Research and Development Unit was tasked to conduct a quantitative evaluation of the handling qualities of the AS350BA following a hydraulic system malfunction. The test programme was to determine if AS350BA flight manual emergency procedures, approach and landing techniques and ship-helicopter operating limits for the AS350BA with a hydraulics malfunction, were likely to require amendment due to control forces, handling qualities or control authority for Royal Australian Navy (RAN) ship borne utility and Australian Army Aviation (AAAvn) training operations. A total of 29.6 hours during 31 test sorties were flown from RAAF Bases Fairbairn and Edinburgh and Cooma Airport from 15 April to 17 June 1997. The AS350BA was easy to fly and displayed generally good handling qualities hydraulics ON. Hydraulics OUT flight was characterised by greatly increased control forces, considerably increased control freeplay and substantially reduced control authority. At high aircraft weights, reduced authority, increased freeplay and high forces in all control axes hydraulics OUT were unacceptable and caused a loss of control during low speed flight testing which could only be recovered by selecting hydraulics ON. The deficiencies in the yaw axis, causing a loss of heading control, were assessed as an initiator to the accident on 10 March 1997 with the major causal factor being the deficiency in the cyclic control authority hydraulics OUT which resulted in aircraft impact with the ground. Consequently, the hydraulics system must be modified or aircraft operations be restricted to ensure that control authority and forces during hydraulics OUT landings are acceptable. A response to the task originators request for an interim envelope recommended operating restrictions which included limiting landing manoeuvres to running landings into wind with a minimum speed of 15 knots increased by half the gust factor (if present) and aircraft Referred Weight to below 1950 kg. Several amendments to flight publications were also recommended based on test results. Further testing is not anticipated to significantly improve these severe limitations on RAN and AAAvn AS350BA operations. Alternatively, for operations outside the safe limit for hydraulics OUT landing, the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent high probability of catastrophic results.

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ANNEXES

1. INTRODUCTION

1.1. Background

1.1.1. Reference A was the Formal Report of the ARDU flight trial concerning the AS350B Squirrel BA upgrade performance validation. In the report ARDU recommended a quantitative evaluation of the handling characteristics of the AS350BA following a hydraulic system malfunction due to high control forces required in this degraded mode. Reference B terminated Task 0168 and the recommendations regarding evaluations of the AS350BA following a hydraulics malfunction were not pursued by agencies outside ARDU. Reference C outlined the preliminary findings of the Accident Investigation Team into the aircraft accident involving A22-004 on 10 Mar 97 and indicated that the accident on 10 Mar 97 was the result of a simulated hydraulics malfunction approach and landing. Reference D was raised by the CO of the Australian Defence Force Helicopter School (ADFHS) to prohibit practice hydraulics emergencies in unit aircraft as a result of the accident and the consequent recommendations in reference C. Notwithstanding reference B, it was considered essential that a hydraulics out performance evaluation be conducted to confirm the recommendations at reference C were appropriate and address the concerns at reference A. Anecdotal evidence from the operators pointed towards a noticeable difference between hydraulics off handling qualities of aircraft in the fleet. For this reason the task was split into two Phases with Phase 1 consisting of a qualitative hydraulics off evaluation of several fleet aircraft and Phase 2 consisting of a quantitative evaluation of a representative aircraft identified in Phase 1.

1.1.2. Phase 1 of the task was completed on 18 April 97. No evidence was found to support the anecdotal evidence of a difference between airframes in the hydraulics off configuration (TEST or ISOL selected). Consequently a representative aircraft was flown to RAAF Edinburgh on 18 April 97 to facilitate Phase 2 testing.

1.2. Task

1.2.1. Reference E tasked OC ARDU to:

a. Conduct a quantitative evaluation of the handling qualities of the AS350BA following a hydraulic system malfunction, with particular emphasis on the landing phase of flight and the impact on extended transits with respect to pilot fatigue and aircraft performance.

b. Determine if AS350BA flight manual emergency procedures were appropriate given the aircraft's hydraulics off handling qualities.

c. Determine if approach and landing techniques outlined in the flight manual and standardisation guide for the AS350BA (for RAN and AAAvn operations) were appropriate given the aircraft's hydraulics off handling qualities.

d. Determine if the Ship-Helicopter Operating Limits (SHOL) for the AS350BA with a hydraulics malfunction were likely to require amendment due to control forces, handling qualities or control authority.

1.3. Definition of Terms Abbreviations and Symbols

1.3.1. All terms used in the conclusions and recommendations of this report are defined at annex A. All abbreviations and symbols used in the report are defined at annex B.

2. RELEVANT CONDITIONS

2.1. Description Of Test Aircraft

2.1.1. The Squirrel AS350BA was a light utility helicopter with an All Up Mass (AUM) of 2100 kg, manufactured by Eurocopter and used in the training and light utility roles by the Army and Navy respectively. The three bladed single main rotor was driven by a Turbomeca Arriel 1B gas turbine engine mounted behind the main transmission. The Squirrel AS350BA Flight Manual (reference F) provides a detailed description of the aircraft.

2.1.2. The BA upgrade was provided by Eurocopter in kit form to enable operators to increase the internal load of the AS350B by 150 kg. The major areas affected by the upgrade included:

a. Structural changes to the transmission deck, horizontal stabiliser and lower fin.

b. Replacement of the main rotor blades with type 355 blades and stiffened frequency adaptors.

c. Tail rotor tab enlarged by 20 mm.

d. Changes to placarding of ASI, torquemeter, N_R , and N_G.

2.1.3. Implementation of the upgrade not only allowed the increase in AUM, but with changes to the rotor system, gave an increase in performance. Consequently, the AS350BA had an internal Maximum AUM (MAUM) of 2100 kg, increasing to 2250 kg for external loads and an increased V_{NE} of 155 KIAS.

2.1.4. A full description of the hydraulic and flight controls is presented in annex C.

2.2. Instrumentation and Test Equipment

2.2.1. Full details of the instrumentation and test equipment are provided at annex D and Non-Standard Modifications to the test aircraft are detailed at annex E.

2.3. Data Reduction

2.3.1. Data reduction methods used for the trial are presented in annex D.

2.4. Specifications

2.4.1. The following specifications were used as a guide in the assessment of the hydraulics OUT handling qualities:

a. MIL-L-8501A: Helicopter Ground Handling and Flying Qualities dated 7 Nov 61, reference G.

b. MIL-F- 83300 Flying Qualities of Piloted V/STOL Aircraft dated 26 Sep 91, reference H.

c. Aeronautical Design Standard 33D - Handling Qualities Requirements for Military Rotorcraft dated July 1994, reference I.

d. Defence Standard 00-970 Vol 1 Rotorcraft dated 31 Jul 84, reference J.

e. Federal Aviation Regulation 27 Normal Category Rotorcraft dated Jan 96, reference K.

f. Federal Aviation Regulation 29 Transport Category Rotorcraft dated Jan 96, reference L.

g. AGARD Report 567 the use of Pilot Rating in Evaluation of Aircraft Handling Qualities dated April 1969 (Cooper-Harper Handling Qualities Rating Scale, included at annex G).

2.5. Aircrew Data

2.5.1. Aircrew experience and other details are presented in annex E.

2.6. Sorties Flown

2.6.1. A total of 31 sorties were flown covering 29.6 hours of flight. A complete list of sorties, hours flown and weather conditions is presented in Table 1 of annex F.

2.6.2. **Time and Place.** Test sorties were conducted at RAAF Bases Edinburgh and Fairbairn with an additional test flight conducted at Cooma in the Snowy Mountains. Flights were conducted from 16 April 97 to 17 Jun 97.

3. TESTS MADE

3.1. Scope of tests

3.1.1. Test Conditions

3.1.1.1. All test flying was conducted in VMC with a gust spread less than 5 Knots and minimal turbulence. A wind velocity not exceeding 10 Knots and within 30 degrees of the landing direction was used for the low speed trim flight control position tests and the landing tests. Flight testing was conducted with the trim selected OFF except where indicated.

3.1.2. Test Limitations

3.1.2.1. All tests were conducted within the normal aircraft limitations as stated in the Flight Manual (reference F). Maximum run on speed for the run on tests was 30 Knots ground speed with the hydraulics in the ISOL or TEST modes. Maximum airspeed for Hydraulics out flight was 70 KIAS.

3.1.3. Test Configuration

3.1.3.1. All flights were conducted with two crew and without a hook or hoist fitted. No external loads were conducted during the trial.

3.1.4. Test Loadings

3.1.4.1. The AS350BA was flown at minimum and maximum AUM and maximum variation of CG possible using combinations of ballast and fuel loadings within the limitations of reference F. Detailed loading information for sorties flown is presented at annex F.

3.2. Method of Test

3.2.1. Ground Tests

3.2.1.1. A full Flight Control Mechanical Characteristics (FCMC) evaluation as described in reference M was conducted with special regard to control authority restriction with the hydraulics selected OFF. These ground tests were repeated each time a flight control run was disassembled or modified and also at cessation of flight testing to confirm the serviceability of the instrumentation.

3.2.2. Flight Tests

3.2.2.1. A shakedown flight was conducted to confirm calibration and serviceability of the instrumentation fitted to the aircraft before test flights were conducted. This included hydraulic and flight control tests from reference N (Flight Test Schedule) to confirm aircraft handling characteristics remained unchanged with the instrumentation installed.

3.2.2.2. The flight tests consisted of qualitative and quantitative analysis of workload and control force during trim flight control positions in the low speed and forward flight envelopes at varying altitudes. Hover and running landings were also conducted at varying altitudes and touchdown airspeeds. Tests were conducted with the hydraulics selected ON, ISOL and TEST.

3.2.2.3. A detailed description of the tests made and test techniques and a table listing full sortie details is presented in annex G.

4. RESULTS AND DISCUSSION

4.1. Flight Control Mechanical Characteristics

4.1.1. General

4.1.1.1. The FCMC of the AS350BA were evaluated with the aircraft parked and shutdown in the ARDU hangar on three occasions and in the ASTA hangar at RAAF Fairbairn at the conclusion of the flight testing. External electrical and hydraulic power were connected to the aircraft for the purposes of the assessments. Although movement of the collective and pedals was possible with the rotors stopped and hydraulics selected to ISOL or TEST, cyclic movement was not. Ground test results are presented in annex H. The FCMC were also assessed in flight over the range and AUM spectrum detailed in annex F. The Control reference (CR) system and Servo reference (SR) system are described at annex C, with FCMC data summarised in Table 1 of this annex. Control positions were measured using the aircraft instrumentation fit as described in annex D.

4.1.2. Collective Lever

4.1.2.1. **Collective Envelope.** The collective lever displacement envelope was measured from the collective control reference position datum with the right pedal forward, aft and in the pedal control reference position. The envelope was assessed with hydraulics in the ON, TEST and ISOL modes. The main rotor servo authority was measured through the full range of collective movement with the cyclic held in the cyclic control reference position (as the cyclic could not be moved in the hydraulics OUT configuration). The main rotor servos were used by both the collective and the cyclic controls. The nomenclature for the servos began from the unit mounted on the forward right of the main transmission as the forward servo and moved anticlockwise to the lateral servo and then the aft servo. The full details of the servo reference system are presented in annex C. The collective envelope was characterised by:

a. **Collective Lever Displacement.** The collective lever travel envelope is shown at annex H, figure 1. The collective lever had unrestricted travel from full down to full up, a distance of 127 mm with the hydraulics selected ON. During hydraulics OUT operation this envelope was unchanged. The lever displacements required in flight did not result in any uncomfortable positioning of the left arm and were easily attained by the flying pilot. The collective lever displacement envelope was satisfactory.

b. **Main Servos Authority in Collective.** Plots of the servo displacements in percentage for collective control input over the full range for hydraulics ON, ISOL and TEST are presented in annex H, figure 2. Table 4.1.2.1 presented below shows the recorded maximum and minimum servo travel for each of the main rotor servos as extracted from figure 2. Full collective movement hydraulics ON did not move the servos through their full travel. The remaining servo movement was required to effect cyclic control at the extremes of collective setting. On average, the servos moved the collective control runs 41 mm for full collective displacement hydraulics ON. With the hydraulics OUT this was reduced to approximately 30 mm (TEST mode). The servo authority with the hydraulics in the TEST mode was reduced by 13-14 % for the lateral and aft servos and 9 % for the forward servo as compared to the hydraulics ON data when considering the total range of the servo movement. As described in annex C, the collective control alters main rotor pitch the same amount through the main hydraulic servos using pressurised hydraulic fluid which provides the force for the movement of the blades.

During reversion to hydraulics OUT flight the forward main, aft main and tail rotor servos move the control rods by direct connection with the control run through a bolt and race arrangement on the actuator assembly as described in annex C. The mechanisation of the degraded mode control caused a freeplay in the system which reduced the authority of the servos in the hydraulics OUT mode. The laterally mounted servo (lateral servo) had a locking pin which seated during the reversion to the hydraulics OUT flight. It was designed to reduce the amount of freeplay in the servo by providing a rigid link, however, the data gathered does not indicate that freeplay was reduced in this servo. Consequently, control authority and margins were dissimilar hydraulics ON and OUT. This caused control inputs with hydraulics OUT to be larger than those required for hydraulics ON to effect the same pitch change at the main rotor. As control margins reduce with increases in weight and density altitude, a point will be reached, depending on the manoeuvre flown, at which adequate margin for control remains with hydraulics ON but insufficient control authority remains for hydraulics OUT operation. Should this occur during a landing manoeuvre hydraulics OUT, a pilot may have insufficient collective control to arrest a rate of descent. This could result in loss of control with the aircraft prematurely touching down causing damage to the aircraft and possible loss of life. The reduced control authority in the collective hydraulics OUT was unacceptable. The hydraulics system must be modified or replaced to ensure that collective control authority in the degraded mode is not reduced below acceptable limits or the aircraft be operated under restrictions to ensure the control authority remains adequate in hydraulics OUT flight. In the absence of any quantitative requirements for allowable reduction in control authority in degraded modes in the FARs (references K and L) the Defence Standard for Rotorcraft (reference J) in paragraph 5.1 of leaflet 600/7 states that in the context of the primary flying controls, overall lost motion refers to an input at the control which does not result in corresponding movement of the associated rotor blade or control surface. Under all operating conditions for fully attended operation, this input should not exceed ±1% of the full range of control displacement. As a guide, the collective channel exceeded this specification in the worst case with a reduction in TEST mode from hydraulics ON of 14%.

Serial	Servo	Collective Position (%)	Servo Travel in Each Hydraulic Mode							
			ON (d)		ISOL (e)			TEST (f)		
(a)	(b)	(c)	[mm]	%	[mm]	%	% reduction from hyd ON	[mm]	%	% reduction from hyd ON
1	Forward	100	81.7	71	78.3	68	3	77.1	67	4
		0	41.4	36	44.9	39	3	47.2	41	5
		range	40.3	35.0	33.4	29.0	6	29.9	26.0	**9**
2	Lateral	100	62.0	75	57.9	70	5	56.2	68	7
		0	20.7	25	24.0	29	4	25.6	31	6
		range	41.4	50.0	33.9	41.0	9	30.6	37.0	**13**
3	Aft	100	61.3	74	56.4	68	6	55.5	67	7
		0	19.1	23	24.0	29	6	24.9	30	7
		range	42.3	51.0	32.3	39.0	12	30.7	37.0	**14**

Table 4.1.2.1: Main Rotor Servo Flight Control Mechanical Characteristics Data for Collective Envelope

4.1.2.2. **Collective Characteristics Hydraulics ON.** The collective forces were qualitatively assessed as moderate with the collective friction wound fully off and hydraulics ON. The friction could be easily adjusted by a rotary friction device at the base of the control, from light friction to an immobilised collective. A constant amount of sliding friction was noticed for control movement with a small break out force needed to initiate motion. This facilitated precise collective control and inhibited any tendency to excite a pilot induced oscillation. The collective appeared well mass balanced and tended to remain in the selected position if not moved by the pilot. The collective characteristics were satisfactory with the hydraulics ON.

4.1.2.3. **Collective Characteristics Hydraulics OUT.** The forces required to move the collective hydraulics OUT were much larger than for hydraulics ON. In general, the force required to move the collective increased with AUM and aft movement of the CG. The reduction in control authority in the collective circuit was manifested as system freeplay when changing the input direction of the collective lever (ie a dead band when reversing control input). This complicated the control task in the heave axis during the transition to low speed flight as frequent downward collective force inputs were required when flaring which necessitated lever movement through the freeplay area before a pitch change at the rotor head took place. This was not generally a problem once established below 30 Knots as a reduction in the collective setting was achieved by reducing the force on the lever (from an up force of 20-35 lbf) which negated the requirement to move through the freeplay range. The collective characteristics were satisfactory apart from the following deficiency:

a. **Collective Forces Hydraulics OUT.** Plots of maximum and minimum control forces versus airspeed up to 30 Knots for In Ground Effect (IGE) trim flight control positions conducted hydraulics OUT are presented in annex I, figure 1. The upper plots denote collective force for Referred Weights of 1700 kg and 1950 kg with a CG variation from 3.17 m to 3.25 m presented for 1950 kg. The plots show that for decrease in airspeed from 30 Knots, increase in Referred Weight or aft movement of the CG the force required increases. For the worst configuration (1950 kg, aft CG), a maximum collective force of 35 lbf upward occured at 15 Knots. Plots of maximum and minimum force for forward flight from 30 to 70 KIAS are presented in annex I, figure 2. Minimum collective forces hydraulics OUT were noted at 40-45 KIAS and increased with airspeed variation from this speed range (ie an increase or decrease in airspeed). Similarly, collective forces increased with aft movement of the CG and increase in Referred Weight. Maximum collective force for an IGE hover point during the test program flown was recorded as 48 lbf upward at 2100 kg (a landing was not attempted). This corresponded to the limiting force the assessing pilot could apply for continuous application during a 5 second time period required for a trim flight control position and was extremely fatiguing. In contrast, at a Referred Weight of 1950 kg, forces were manageable to allow landings to be completed. In the training environment, the high forces would be extremely fatiguing to an ab-initio helicopter student. At maximum weight and higher density altitudes (Canberra routinely reaches 3500 ft DA in summer) these forces would increase. This may prevent a pilot (student or instructor alike) from adequate control of the heave axis to avoid uncommanded rates of descent during a hydraulics OUT landing following system failure. This is likely to bring about an uncontrolled touchdown resulting in damage to the aircraft and possible loss of life. The high collective forces hydraulics OUT were very likely to be a contributing factor to the aircraft loss of control which caused the crash on 10 March 1997. The high forces in the collective control hydraulics OUT were unacceptable. The forces must be reduced to acceptable limits or a weight restriction be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration. Alternatively, for operations at weights above the safe limit for hydraulics OUT operation, the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent probability of catastrophic results.

4.1.3. Cyclic Stick

4.1.3.1. **Cyclic Envelope.** The cyclic envelope for the hydraulics selected ON with the collective in various positions is presented at annex H, figure 3. The figure shows scales for displacement from the fully forward and left position to the fully aft and right position in percentage and mm. The stick could be moved a maximum of 248 mm longitudinally and 240 mm laterally. A square envelope was noted which was qualitatively assessed in flight with adequate control margins (greater than 10%) existing for the tests conducted hydraulics ON. A variation in the envelope was noted for varying collective positions of up to 3% as shown in the figure. This was due to the effect of the limit stops in the mixing unit for both cyclic and collective as the controls for the main rotor were actuated through the same circuit. The difference was due to mechanisation of the control run. The pilot had no difficulty in reaching the extremes of lateral or longitudinal cyclic travel required for the manoeuvres flown hydraulics ON. The cyclic stick envelope was satisfactory with the hydraulics ON.

4.1.3.2. **Main Servos Authority in Cyclic.** The total displacement of the main rotor servos was measured with the hydraulics ON and required the movement of the cyclic and collective in varying combinations to effect full movement of each servo. A diagram of the servo displacements with collective movement for the main servos is presented at annex H, figure 2. The full details of the servo reference system are presented in annex C. The hydraulic system prevented movement of the cyclic control with hydraulics OUT so that cyclic servo authority could not be measured in the degraded modes. However, as there were only direct linkages between the cyclic control and the main rotor servos and the cyclic control was actuated through the same set of servos, a similar control reduction with hydraulics OUT was assumed. This would mean that the cyclic could be affected by the same amount in each of the axes corresponding to the particular servo control. For the cyclic control, the laterally mounted servo on the main transmission controlled pitch and the fore and aft mounted servos controlled the roll axis. Extrapolation of the data for the collective circuit indicated that a reduction of approximately 14% in the longitudinal axis and 12% in the lateral axes of the cyclic authority would occur at sea level. For the same reasons as listed in paragraph 4.1.2.1.b, there would be currently cleared areas of the flight envelope where insufficient control margin remains in cyclic, hydraulics OUT, for control of the aircraft. Cyclic control margins were predicted to be near their minimums when hovering downwind at maximum aft CG and high weights hydraulics OUT. A22-004 was in this situation when it crashed and it is highly likely that this control authority deficiency in cyclic was a contributing factor. The reduction in main hydraulic servo authority in cyclic control was unacceptable. The hydraulics system must be modified to ensure that cyclic control authority in the hydraulics OUT mode is not reduced below acceptable limits or aircraft operations be restricted to ensure the control authority remains adequate in hydraulics OUT flight. Alternatively, for operations where an adequate control margin hydraulics OUT is not available, the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent probability of catastrophic results pending a risk analysis.

4.1.3.3. **Cyclic Characteristics Hydraulics ON.** The stick forces were assessed in flight with the cyclic trim system selected ON and OFF. The friction could be easily adjusted by a rotary friction device at the base of the cyclic from light friction to an immobilised cyclic. Qualitatively, with the friction fully off, the control forces were light with a constant amount of sliding friction noticed for movement of the stick. This assisted the pilot to smoothly select a stick position accurately and inhibited any tendency toward excitation of a pilot induced oscillation. The stick displayed neutral control centring with a small break out force with the trim disengaged. The lateral and longitudinal axes appeared well harmonised with qualitatively similar forces required for displacement in each direction and small break out forces giving a pleasant feel to the cyclic with the trim engaged. The cyclic characteristics with the hydraulics ON were satisfactory.

4.1.3.3. **Cyclic Characteristics Hydraulics OUT.** The forces required to move the cyclic hydraulics OUT were much larger than for hydraulics ON. As noted in the collective, the force required to move the cyclic generally increased with Referred Weight and aft movement of the CG. The cyclic hydraulics OUT was characterised by:

a. **Cyclic Hydraulics OUT Freeplay.** Figure 3, in annex I shows control positions for a 10 Knot running landing attempted at 1950 kg, ISA sea level conditions. The longitudinal cyclic was varying ± 15% and the lateral cyclic was varying ±10% during the attempted touchdown. The reduction in control authority in the cyclic circuit was manifested as system freeplay when changing the input direction of the cyclic lever through the control feedback neutral point (ie the aircraft flight condition where the magnitude of the feedback forces in the cyclic were at a minimum). The freeplay, or dead band of control movement, made precise control in the longitudinal and lateral axes required during hover or running landings below 15 Knots extremely difficult, as constant movement through the freeplay was required before a cyclical pitch change at the rotor head took place. Maximum tolerable pilot work load in the cyclic axes was reached in order to maintain control of the aircraft. This characteristic was another likely contributing factor to the loss of control situation which preceded the aircraft accident on the 10 Mar 97. The cyclic hydraulics OUT freeplay was unacceptable. The recommendation in paragraph 4.1.3.2 also embraces the deficiency highlighted in this sub-paragraph.

b. **Longitudinal Cyclic Forces Hydraulics OUT.** Plots of maximum and minimum cyclic control forces versus airspeed up to 30 Knots for IGE trim flight control positions conducted hydraulics OUT are presented in annex I, figure 1. The longitudinal cyclic plots denote force for Referred Weights of 1700 kg and 1950 kg with a CG variation from 3.17 m to 3.25 m presented for 1950 kg. The plots show that for decrease in airspeed from 30 Knots, an increase in Referred Weight or aft movement of the CG, forward force required on the cyclic generally increases. At 1950 kg, aft CG and run on speeds of 15-20 Knots, a maximum force of approximately 25 lbf forward occurred. Plots of maximum and minimum force for forward flight from 30 to 70 KIAS are presented in annex I, figure 2. Minimum longitudinal cyclic forces hydraulics OUT were noted at 40-50 KIAS and increased with airspeed from this speed range although the force gradient was not as steep as the low speed case. Similarly, in forward flight, longitudinal cyclic forces increased with aft movement of the CG and increase in Referred Weight. Maximum longitudinal cyclic force for low speed operation during the test program flown was recorded as 32 lbf forward at 1700 kg during a hover landing. annex I, figure 4 shows force plots of controls for a 10 knot attempted run on landing at 1950 kg. Control force reversals in longitudinal cyclic from a push force of 10 lbf to a pull force of 25 lbf every 3 seconds were required to maintain longitudinal velocity which exceeded the maximum tolerable pilot workload in longitudinal cyclic and the landing had to be aborted (HQR 9). At airspeeds above 15 Knots, the point where control force reversals occurred with aircraft Referred Weights of 1950 kg, the constant high forces encountered of approximately 20-35 lbf were very fatiguing to the flying pilot but were manageable and tolerable as a degraded mode of operation. The high cyclic longitudinal force reversals during hydraulics OUT landing at night to a ship below 15 Knots and above 1950 kg Referred Weight would be extremely fatiguing and would exceed the capabilities of an average pilot when coupled with the freeplay deficiency in the system. This is likely to prevent adequate pitch rate control and cause the aircraft to crash on landing resulting in damage to the aircraft and possible loss of life. The high forces in the longitudinal cyclic control axis hydraulics OUT were unacceptable. The hydraulics OUT longitudinal cyclic control forces must be reduced to acceptable limits or Referred Weight and minimum airspeed of 15 Knots restrictions be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration. Alternatively, for operations at weights above the safe limit for hydraulics OUT

operation, the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent probability of catastrophic results.

c. **Lateral Cyclic Forces Hydraulics OUT.** A plot of lateral airspeed versus lateral cyclic control force for low speed flight at 1950 kg for 30 degree green and red winds is presented in annex I, figure 5. The plot shows that the lateral cyclic force required increased with crosswind in magnitude and variation. Hence, when attempting a crosswind landing, lateral cyclic force was required to the windward side. For winds from ahead, minimum lateral cyclic forces were noted at 40-45 KIAS and generally increased in magnitude with airspeed variation from this speed range (ie an increase or decrease in airspeed). A similar magnitude increase to the longitudinal and collective channels was also noted with aft movement of the CG and increases in Referred Weight. The lateral force requirements for forward flight were less predictable than for longitudinal cyclic and tended toward a left cyclic force increase for increases in airspeed above the minimum drag speed. Control force harmonisation in the cyclic was extremely poor hydraulics OUT. Although the control forces in lateral cyclic were quantitatively lower than longitudinal cyclic, qualitatively they appeared far worse to the assessing pilot. This was due to the reduced limit force of application in lateral cyclic by the pilot and increased with difficulty as the functional reach of the pilot was reached at aft CGs with forward migration of the cyclic. Additionally, for green winds, cyclic forces were such that the stick tended to move through the gap between the thumb and fingers, further complicating the task. Added to this were the difficulties in dealing with the simultaneously high longitudinal cyclic forces in this configuration. In low speed flight with a 30 knot wind from green 30 direction, adequate lateral velocity control for running landing with no drift was not attainable with maximum pilot compensation in lateral cyclic with forces varying continuously from zero up to 15 lbf every 3 seconds (HQR 7). Consequently, only into wind landings could be completed safely. The high lateral cyclic forces would be extremely fatiguing to an average squadron pilot and would probably exceed their capability to maintain adequate roll rate control when attempting a crosswind hydraulics OUT landing to a ship at night. This would cause the aircraft to roll over on touchdown with consequent aircraft damage possible and loss of life. The high forces in the cyclic lateral control axis hydraulics OUT were unacceptable. The hydraulics OUT cyclic control forces must be reduced to acceptable limits or a weight restriction be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration and landings are only conducted into wind. Alternatively, for operations at weights above the safe limit for hydraulics OUT operation the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent probability of catastrophic results.

4.1.4. Tail Rotor Pedals

4.1.4.1. **Tail Rotor Pedal Envelope.** The yaw pedals consisted of a set of L shaped brackets which could be interchanged to facilitate fore/aft adjustment. The yaw control envelope was measured with the pedals adjusted fully forward with the full movement of the collective and the cyclic in the control reference position. A diagram of pedal and servo travel is presented at annex H, figures 4 and 5 respectively.

a. **Pedal Travel.** The total pedal travel was 70 mm and was independent of the orientation (forward or aft) of the pedals. The change in yaw pedal position was 60 mm further aft when the pedals were interchanged to the aft position. The pedal travel was unchanged hydraulics ON and hydraulics OUT. The assessing pilot was easily and comfortably able to reach the extremes of yaw pedal travel. The yaw pedal envelope was satisfactory.

b. **Tail Rotor Servo Authority.** The tail rotor servo extension displacement is presented in annex H, figure 5 and includes plots of the servo displacement for control input for hydraulics ON, ISOL and TEST. A diagram of the pedal servo travel versus collective position is also presented in annex H, figure 6. The yaw pedal envelope was unaffected by cyclic control position but was reduced by 20% left pedal forward when the collective was in the full up position. This was due to the effect of the collective to yaw interlink which fed in right pedal with increases in collective. A diagram and description of the interlink system is contained in annex C. The interlink was a design feature to assist the pilot (or AFCS when fitted) by reducing the amount of right pedal input required to counteract main rotor torque with increases in collective. The reduction in available minimum tail rotor pitch due to the interlink was not considered a problem. Table 4.1.4.1 presented below shows the recorded maximum and minimum servo travel for the tail rotor servo as extracted from figure 6. The pedals moved the tail rotor servo 83.6 mm for full pedal displacement hydraulics ON. With the hydraulics OUT and the collective down this was reduced to approximately 64.3 mm (TEST mode), a 23 % reduction. A 27 % reduction in displacement envelope was similarly noted for a mid collective setting. Results in the ISOL mode indicated slightly less reduction, however during ground testing it was determined that the tail rotor servo was still receiving 150 psi of assistance from the hydraulic pump. The hydraulic assistance would not be available in the case of failure of the system, hence the failure mode was most closely modelled by the selection of TEST switch. The tail rotor servo differs from the main servos in that it does not have an accumulator nor does it have a locking pin fitted as per the lateral main servo. The tail rotor servo suffered from the same reduction in authority as the main servos caused by the mechanisation of the degraded control (hydraulics OUT) mode as described in annex C and paragraph 4.1.2.1.b above. Also, aerodynamic feedback forces were felt immediately in the yaw channel as no accumulator pressure was available to the servo. Control authority and margins were dissimilar hydraulics ON and OUT causing control inputs required hydraulics OUT to be larger than those for hydraulics ON to effect the same pitch change at the tail rotor. During a trim flight control position test at 2100 kg and 25 Knots of steady wind from directly ahead in the hydraulics ISOL mode in a 5 foot hover taxi, a sudden onset of left yaw was noted. Maximum application of right pedal failed to arrest the yaw rate as the heading passed 30° left of the trim position. The hydraulics were selected ON and control of the aircraft was regained with the heading some 60° left of the trim position. The right pedal had reached greater than 88% of its travel as the collective to yaw interlink spring pressure was noted through the control. The sudden yaw rate was very surprising to the assessing pilot and flight test engineer and the pilot found it impossible to make the required input at a sufficient rate to prevent the departure in yaw axis. Control of the heading ±20° at 25 knots wind from ahead in the hydraulics ISOL mode was not possible with maximum pilot compensation in the yaw channel and reversion to hydraulics ON flight was required to regain control of the aircraft (HQR 10). Control margins will reduce with increases in Referred Weight. Thus, at weights below 2100 kg AUM, a density altitude will be reached where insufficient pedal control authority remains to arrest a yaw rate or maintain heading hydraulics OUT during landing manoeuvres because of the servo control authority reduction. An attempted landing hydraulics OUT in this flight condition will cause loss of control of the yaw axis and the aircraft will probably crash causing damage to the aircraft and possible loss of life should a hydraulics OUT landing be attempted after a system failure. This yaw control authority reduction was most likely a casual factor to the crash on 10 March 97. The reduced tail rotor control authority in the hydraulics OUT mode was unacceptable. The hydraulics system must be modified to ensure that pedal control authority in the degraded mode is not reduced below acceptable limits or the aircraft be operated under restrictions to ensure the control authority remains adequate in hydraulics OUT flight.

Serial (a)	Collective Position (b)	Right Pedal Position % (c)	Tail Rotor Servo Travel in Each Hydraulic Mode: ON (d) [mm]	ON (d) %	ISOL (e) [mm]	ISOL (e) %	ISOL (e) % reduction from hyd ON	TEST (f) [mm]	TEST (f) %	TEST (f) % reduction from hyd ON
1	Down	100	83.6	100	75.24	90	10	72.73	87	13
		0	0	0	6.688	8	8	8.36	10	10
		range	83.6	100	68.55	82	18	64.37	77	**23**
2	Mid	100	83.6	100	77.75	93	7	77.75	93	7
		0	4.18	5	15.05	18	13	20.9	25	20
		range	79.42	95	62.7	75	20	56.85	68	**27**
3	Up	100	83.6	100	79.42	95	5	78.58	94	6
		0	16.72	20	25.92	31	11	25.92	31	11
		range	66.88	80	53.5	64	16	52.67	63	**17**

Table 4.1.4.1: Tail Rotor Servo Flight Control Mechanical Characteristics Data for Pedal Envelope

4.1.4.2. **Pedal Characteristics Hydraulics ON.** The yaw pedals were assisted by a hydraulic servo but could also move the tail rotor by direct connection in a degraded mode. The pedal forces with hydraulic assistance were qualitatively light. Pedal operation revealed a constant amount of sliding friction over the envelope with a small break out force needed to initiate movement. This facilitated accurate control and inhibited any tendency to overshoot the required pedal position when precise control movements were needed (ie out of wind hovering). The yaw pedal characteristics hydraulics ON were satisfactory.

4.1.4.3. **Pedal Characteristics Hydraulics OUT.** Pedal forces increased noticeably when the degraded mode was selected. Pedal control in the hydraulics OUT configuration was complicated by the collective pitch to yaw interlink. Collective movements fed back forces to the pedals through the interlink which tended to move the pedals opposite to the direction required for balanced flight with collective movement (ie the right pedal moved aft for collective increase). This was very unpleasant during the latter stages of a transition to low speed flight, as the pilot needed to resist the induced pedal movement from collective variations. In isolation, the interlink collective feedback was tolerable hydraulics OUT. The following deficiencies were identified in the pedal characteristics hydraulics OUT:

a. **Pedal Hydraulics OUT Freeplay.** Figure 3 in annex I also shows a yaw pedal position plot for the attempted landing at 10 knots. The plot reveals pedal inputs of ±20% which failed to maintain adequate heading control. The reduction in control authority in the pedal circuit also manifested itself as system freeplay when changing the input direction of the pedals. The freeplay differed from the other controls because of the variability of the control feedback neutral point. The freeplay or dead band of control movement made precise control in the yaw axis during low speed flight extremely difficult as constant movement through this freeplay was required before a tail rotor pitch change took place. This complicated yaw control as the freeplay delayed the control response when attempting to counter gusts or change trim conditions. Consequently, heading departures were difficult to prevent and more difficult still to recover. This was highly likely to be an additional contributing factor to the accident on the 10 Mar 97. The pedal hydraulics

OUT freeplay was unacceptable. The recommendation in paragraph 4.1.4.1.b. covers the deficiency highlighted in this sub-paragraph.

b. **Pedal Forces Hydraulics OUT.** Plots of maximum and minimum control forces versus airspeed up to 30 Knots for IGE trim flight control positions conducted hydraulics OUT are presented in annex I, figure 1. The pedal force plots detail results for Referred Weights of 1700 kg and 1950 kg with a CG variation from 3.17 m to 3.25 m presented for 1950 kg. The yaw pedal force plots show differential pedal force (ie left pedal minus right pedal). Total force on the pedals generally increases for decrease in airspeed from 30 Knots, increase in Referred Weight or aft movement of the CG. For the worst configuration (1950 kg, aft CG) maximum force of 110 lbf on the right pedal occurred at 15 Knots. Plots of maximum and minimum force for forward flight from 30 to 70 KIAS are presented in annex I, figure 2. Minimum pedal inputs hydraulics OUT in forward flight were noted at 40-45 KIAS with left pedal increasing with airspeed as the vertical stabiliser unloaded the tail rotor. As with the other controls, peak forward flight forces increased with aft movement of the CG and increase in Referred Weight. A plot of pedal differential control forces for an aborted landing at 1950 kg is presented in annex I, figure 4. Although the differential pedal forces show a maximum of 130 lbf, the actual force on the right pedal was 160 lbf with 30 lbf applied to the left pedal. These forces were excessive and prevented the pilot from maintaining adequate heading control for touchdown during a running landing. At high weights and speeds below 40 Knots the forces encountered in the pedals were fatiguing to the flying pilot, even in the short term. These high forces would be very fatiguing to an ab initio student and coupled with the freeplay in the system would make control of the yaw axis extremely difficult on approach to land even at low weights. At high weights the forces would exceed the capability of the student to maintain yaw control. An attempted landing with a hydraulics failure at maximum AUW and aft CG at sea level on an ISA day is likely to result in a loss of yaw control and consequent roll over on landing. The extremely high control forces required in the pedal controls hydraulics OUT was a major contributing factor in the accident of 10 March 1997. The high forces in the tail rotor pedal control hydraulics OUT were unacceptable. The forces must be reduced to acceptable limits or a weight restriction be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration. Alternatively for operations at weights above the safe limit for hydraulics OUT operation, the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent probability of catastrophic results on attempted landing.

4.1.5. Limit Control Forces and Specifications

4.1.5.1. Information on control force limitations was extracted from references G, H, I, J, K and L from the following locations:

a. DEFSTAN - leaflet 600/6 amdt 7 dated sep 89, Table 4.

b. MIL SPEC 8501A - Paragraph 3.5.8.

c. MIL SPEC 83300 - Table 13 of section 3.5.

d. ADS33D Table 4 of Section 3.6.

e. FARs - Section 27.397 and Section 29.397.

4.1.5.2. Table 4.1.5.2 lists the limit Control Force (CF) requirements in flight from the specified references. In each of the military standards (Serials 1 to 4) precise definition of the limit control forces during degraded mode operation are detailed. Additionally, Serials 2 to 4 list limiting Control Force Transients (CFT) in recovery from the degraded mode and then list maximum forces for landing manoeuvres. References K and L do not refer to pilot forces for safe control of the rotorcraft in a degraded mode or during normal flight but list limiting forces to which the control runs must be designed to withstand without yielding through pilot input or otherwise (ie structural limitation). This means that control forces in excess of this design criteria may result in the control run deforming or, at worst, structural failure where the installation of the control run is at the minimum standard.

Serial (a)	Specification or Force Origin (b)	Collective (lbf) (c)		Longitudinal Cyclic (lbf) (d)		Lateral Cyclic (lbf) (e)		Pedals (lbf) (f)	
		CF	CFT	CF	CFT	CF	CFT	CF	CFT
1	MILSPEC 8501A reference G	25	-	25	-	15	-	80	-
2	MILSPEC 83300 reference H	7	7	20	40	15	20	40	80
3	ADS 33D reference I	10	10	20	40	15	20	40	80
4	DEFSTAN (RW) reference J	10	20	5	10	5	10	15	30
5	FAR 27/29 references K&L (Force design limits for control run)	not detailed	-	100	-	67	-	130	-

Table 4.1.5.2: Specification Force Limits for Degraded Mode Operation of Rotorcraft

Note: Tables 4.1.5.2 and 4.1.5.3 must be read in conjunction with paragraphs 4.1.5.2 and 4.1.5.3.

4.1.5.3. Table 4.1.5.3 lists the peak control forces encountered in each control axis for all tests flown during task flying landing and forward flight manoeuvres and then compares them to limit control forces from the specified references. For operation of the AS350BA hydraulics OUT, results of the flight tests for control forces for references G to J, in all flight control axes and limit forces in references K and L for the design strength of the tail rotor control run were exceeded. Additionally, reference K and L in paragraphs 27.151 and 29.151 state that for all flight conditions:

> ***Flight Controls.*** *Longitudinal, lateral, directional and collective controls may not exhibit excessive break out force, friction, or preload. Control System forces and freeplay may not inhibit a smooth, direct rotorcraft response to control system input.*

4.1.5.4. This is the only reference to flight control mechanical characteristics for helicopters in these specifications. The AS350BA Hydraulics OUT failed to meet these FAR requirements also. The assessing pilot found the MILSPEC 8501A limits to be appropriate for maximum control forces tolerable for landing, with adequate margin for recovery from gusts and allowance made for skill levels of ab-initio students or degraded useable cue environments encountered in night ship borne operations, when considering a hydraulics OUT landing.

Serial (a)	Specification or Force Origin (b)	Collective (lbf) (c)	Longitudinal Cyclic (lbf) (d)	Lateral Cyclic (lbf) (e)	Pedals (lbf) (f)
1	Maximum Test Flight Forces During Landing Manoeuvre	48	32	18	160
2	MILSPEC 8501A Exceedance lbf / %	23 **90%**	7 **28%**	3 **20%**	80 **100%**
3	MILSPEC 83300 Exceedance lbf / %	41 **585%**	12 **60%**	3 **20%**	120 **300%**
4	ADS 33D Exceedance lbf / %	38 **380%**	12 **60%**	3 **20%**	145 **300%**
5	DEFSTAN (RW) Exceedance lbf / %	38 **380%**	27 **540%**	13 **360%**	145 **970%**
7	FAR 27/29 Exceedance lbf / %	not detailed	not exceeded	not exceeded	30 **23%**

Table 4.1.5.3: Specification and Test Results Force Comparison

Note: Tables 4.1.5.2 and 4.1.5.3 must be read in conjunction with paragraphs 4.1.5.2 and 4.1.5.3.

4.2. Low Speed Handling Qualities

4.2.1. **General.** The low speed handling characteristics hydraulics OUT were assessed over the flat terrain (smooth bitumen and grass surfaces) of the runway and taxiway areas of RAAF Bases Edinburgh and Fairbairn and Cooma Airport. Wind speed for all tests was less than 10 Knots. The trim was disengaged for all low speed testing. Sortie details and tests conducted are listed in detail in annexes F and G. Low speed tests were initially conducted hydraulics ON to confirm adequate control margins before proceeding to the hydraulics ISOL and TEST modes for each CG and Referred Weight combination. Testing was approached incrementally from a control margin standpoint as deficiencies had been identified in the FCMC evaluation prior to the commencement of flight tests. Thus, each Referred Weight was approached from an aft CG to a forward CG to provide maximum initial control margin.

4.2.2. As a result of the loss of control in the HYD ISOL mode at 2100 kg, a major revision of the test programme took place. After consultation with the tasking agency and operators, it was decided that the test programme should be limited to the maximum available CG range at aircraft Referred Weight of 1950 Kg for operations hydraulics OUT. Consequently, the full range of available CG variation was evaluated at this Referred Weight through trimmed flight control position tests and running landings at wind speeds below 30 Knots. The following paragraphs refer to these tests conducted for into wind landings between 15 and 30 Knots.

4.2.3. **Running Landing.** Running landings were conducted to level grass at airspeeds below 30 Knots into wind in ISOL and TEST modes. Annex I, figures 6 and 7 show control force and control position plots for a running landing at 1950 kg with an aft CG and touchdown speed of 20 Knots. There was a marked reduction in control forces and control activity (as evidenced by the reduction in cyclical inputs) in all axes when compared to the 10 knot aborted landing in annex I, figure 4. Normal running landings hydraulics OUT were initiated via a long shallow approach into wind with the aircraft decelerated to 40-45 KIAS. At approximately a half mile from intended

touchdown point the aircraft was slowed to a ground speed corresponding to the required wind speed through the rotor disc using longitudinal cyclic inputs. The aircraft was then cushioned to the ground with collective and kept straight with pedal at the required touchdown point. Forward force on the cyclic was required to maintain airspeed during final stages of the approach, especially just prior to landing at all touchdown airspeeds above 15 Knots. The forward force requirement increased with reduction in airspeed and aft movement of the CG. Bleed valve operation at some AUMs introduced torque transients which had to be countered by pedal inputs. A small, gentle reduction in collective after the skids had contacted the ground was needed to assist in maintaining firm contact with the ground. This also reduced run on length. Right cyclic and generally left pedal inputs were introduced after touchdown to maintain a straight run on and heading as the aircraft decelerated. For most conditions, maximum workload was equally shared by longitudinal cyclic and pedal. Control inputs were clear of the 10% margins and control forces were manageable. The landing manoeuvre was difficult to fly with the aircraft demonstrating poor handling qualities, however, safe repeatable landings could be made into wind with a minimum of 15 knots through the disc on touchdown. The manoeuvre was demonstrated in all CG conditions tested for referred weights below 1950 kg and it was considered tolerable as a degraded mode with the aforementioned restrictions applying. The running landing characteristics for into wind landings above 15 Knots and below 1950 kg Referred Weight were satisfactory.

4.2.4. **Gust Alleviation.** The gust response of the aircraft was assessed during low airspeed trim flight control positions and landing, during flights conducted at Canberra (5-10 Knot gusts). The aircraft response was a divergent pitch, roll or yaw rate in any combination of axes with any gust which required step changes in forces on controls to maintain trim. The poor gust response combined with the very poor cyclic FCMC of the aircraft at speeds below 15 Knots made workload increase with gusty conditions when compared to calm conditions. To alleviate the high workload in this condition, the minimum airspeed was increased by half the gust factor to prevent inadvertent excursion below 15 Knots and to diminish the overall force requirements, reducing the magnitude of the step force changes due to gusts. The same arguments as detailed in paragraph 4.1.3.4.b.b. apply to ensuring the approach airspeed does not reduce below 15 knots with gusts. The gust response of the aircraft below 1950 kg Referred Weight was unacceptable and the minimum approach speed hydraulics OUT must be increased in gusty conditions by half the gust factor to ensure that speed reduction into the area where an unacceptable reduction of handling qualities for landing does not occur.

4.3. Forward Flight Handling Qualities

4.3.1. **General**. Forward flight handling qualities were assessed during trim flight control position tests and Acceleration-Deceleration tests in the conditions detailed in annex G over the full CG and AUM range to 2100 kg .

4.3.2. **Acceleration - Deceleration.** Plots of control forces during an acceleration-deceleration test at 5000 ft PA, for 1950 kg and 2100 kg are presented in annex I, figure 8. The plots show peak forces of collective at 50 lbf, cyclic at 20 lbf left laterally and 22 lbf forward longitudinally and right pedal at 85 lbf. The aircraft was transitioned over this airspeed range in less than 120 seconds. The 10% control margins were not approached during these tests. The forces for transition were very high but were tolerable as a transient manoeuvre in a degraded mode. Handling qualities during accelerative or decelerative flight hydraulics OUT were satisfactory.

4.3.3. **Trim Flight Control Positions.** Forces for forward flight from 30 to 70 Knots were evaluated during trim flight control position tests. Plots of forces for trim flight control positions in forward flight are presented in annex I, figure 2. The control forces were high in all axes but were manageable for short periods. Workload reduction was effected by frictioning the collective control such that the control maintained a constant position but was still able to be moved by the pilot in case of engine failure. Some assistance was also gained by engaging the trim and displacing the

cyclic toward the force required for a static position away form the trim point then releasing the trim button. In this way the trim force gradient could be used to offset the hydraulic OUT force requirements. This had to be done well away from the ground as a pitch or roll rate had to be accepted whilst the cyclic was retrimmed. No method of reducing the force requirements on the pedals was identified. Frictions and trims were disengaged for landing manoeuvres. Hydraulics OUT workload in forward flight for day VMC conditions was satisfactory as a degraded mode. Workload during Night/IMC flight with the hydraulics OUT was not assessed but is highly likely to be unacceptable for prolonged flight in a reduced useable cue environment (Night/IMC). Consequently, hydraulics out flight in Night/IMC should be discontinued as soon as possible. The recommendations in annexes K and L address IMC and Night Flight for hydraulics OUT operation.

4.4. Referred Weight

4.4.1. Control feedback forces increase and control margins decrease with increase in density altitude for the AS350BA. To allow for this during aircraft hydraulics OUT operation where critically high forces were encountered, a Referred Weight technique was used. The objective of using the technique was to ensure that the aircraft's control margins and forces were comparable under different atmospheric conditions. Referred Weight is defined as the aircraft weight divided by the density ratio. The method of using Referred Weight to maintain constant control margins and control forces is detailed in the DSTO report 'The Referred Weight Flight Test Technique Applied to First of Class Flight Trials' (reference O). The analytical results in the report agreed with the simulation and actual flight tests, validating the theory. Annex L presents the Referred Weight calculations used during the tests. Sorties at higher density altitude but reduced AUM (same Referred Weight) were flown during the trial at Canberra and Cooma to ensure that the weight adjustment calculated was valid. Results of these tests agreed with data gathered at sea level conditions. As discussed in the preceding paragraphs, adequate control margins and control forces enabled safe, repeatable hydraulics OUT landings at Referred Weights below 1950 kg. With increase in density altitude from sea level, aircraft AUM had to be reduced to maintain a constant Referred Weight. Figure 1 in annex L was used for this purpose in the test programme and required knowledge of the OAT and pressure altitude to determine the MAUM corresponding to 1950 kg Referred Weight. Based on test results, safe landings at Referred Weights significantly greater than 1950 kg are not expected to be achievable. Although control forces and margins are also affected by CG variation there is very little scope for expansion of the safe Referred Weight landing envelope with respect to CG. Within the scope of the test, attempted landings hydraulics OUT at Referred Weights greater than 1950 kg were unacceptable. The maximum Referred Weight for safe hydraulics OUT landings must be limited to 1950 kg.

4.5. Flight Documentation

4.5.1. **Flight Manual.** The military AS350BA Flight Manual (reference F) was created by staff at the ADFHS using the earlier military B model and the Eurocopter Flight Manual for the aircraft (reference P). Several deficiencies were noted in the flight manual in performance section and other areas of the manual. However, some of these were deemed to be outside the scope of this report but are subject to a further ARDU flight test programme in response to a request from HQ AVN SPT GP. The following deficiencies were considered relevant:

a. **Hydraulics out Airspeed Limit.** A maximum airspeed of 70 KIAS was recommended in reference P for hydraulics out flight. This information was not included in the military flight manual for the BA model. This limitation should be adopted as the maximum airspeed limit hydraulics out as per the original equipment manufacturers instructions to ensure safety of flight during hydraulics out operations. The absence of a flight manual

hydraulics out airspeed limit was unsatisfactory and it is highly desirable that the following statement be inserted into section 5 of the current flight manual for the AS350BA (reference F):

Maximum airspeed for hydraulics out flight is 70 KIAS

b. **Flight Manual Hydraulic System Emergency Procedures, Limits and Flight Characteristics.** Emergency procedures, specific limitations and flight characteristics for hydraulics OUT flight have been summarised and are presented in annex J. The details incorporate the results of the trial as they apply to reference F. As a result of data gathered during the testing, existing flight manual emergency procedures, limitations and flight characteristics explanations were unsatisfactory. It is highly desirable that revised emergency procedures, limits and flight characteristics presented in annex J incorporating trial results be included in the flight manual (reference F).

4.5.2. **Training Operations.** In view of the results of the trial with respect to safe limits for hydraulics OUT landings, additional recommendations are considered appropriate during training operations which will minimise the risk of an aircraft accident. In this regard, the conduct of hydraulics OUT training operations was unsatisfactory and it is highly desirable that the recommendations in annex K are incorporated into operators training guides.

4.5.3. **Flight Test Schedule.** The following deficiencies were noted in reference N, AS350BA Flight Test Schedule:

a. **Hydraulics OUT Hover Landing.** A requirement for a hover landing at the completion of maintenance test flights was listed in the Test Schedule. This is in conflict with the manufacturers requirements in reference P (Eurocopter Flight Manual). This is believed to be an old B model requirement which was not changed after the aircraft was modified to BA standard. In the light of the unacceptable handling qualities below 15 knots airspeed, hydraulics OUT landings to the hover may cause loss of control and result in an aircraft crash. The requirement for a hydraulics OUT hover landing at the completion of a maintenance test flight was unacceptable and the Flight Test Schedule must be amended to reflect the requirement to land with the minimum speed and other recommendations laid down in annex J.

b. **100 KIAS Hydraulics OUT Flight.** A requirement for flight hydraulics OUT at 100 KIAS was also listed in the Test Schedule. This is in conflict with the recommended airspeed of 70 KIAS in reference P (Eurocopter Flight Manual) for hydraulics out flight. This information was not included in the military Flight Test Schedule for the BA model. This limitation should be adopted as the maximum airspeed limit hydraulics out as per the original equipment manufacturers instructions to ensure safety of flight during hydraulics OUT operations. The requirement to fly at 100 KIAS hydraulics out during maintenance test flights was unsatisfactory and it is highly desirable that reference N be amended to reflect that the maximum airspeed for hydraulics OUT operations should be 70 KIAS. Accordingly, paragraph 410 and paragraph 10 of annex C to Section 4 of reference N should have 100 KIAS replaced with 70 KIAS.

5. CONCLUSIONS

5.1. General Conclusions

5.1.1. The AS350BA was easy to fly and displayed generally good handling qualities hydraulics ON. Hydraulics OUT flight was characterised by greatly increased control forces, considerably increased control freeplay and substantially reduced control authority. At high aircraft weights, reduced authority, increased freeplay and high forces in all control axes hydraulics OUT were unacceptable and caused a loss of control during low speed flight testing which could only be recovered by selecting hydraulics ON. The deficiencies in yaw axis causing a loss of heading control were assessed as an initiator to the accident on 10 March 1997 with the major causal factor being the deficiency in the cyclic control authority hydraulics OUT which resulted in aircraft impact with the ground. Consequently, the hydraulics system must be modified or aircraft operations be restricted to ensure that control authority and forces during hydraulics OUT landings are acceptable. A response to the task originator's request for an interim envelope recommended operating restrictions which included limiting; landing manoeuvres to running landings into wind with a minimum speed of 15 Knots increased by half the gust factor (if present) and aircraft Referred Weight to below 1950 kg. Several amendments to flight publications were also recommended based on test results. Further testing is not anticipated to significantly improve these severe limitations on RAN and AAAvn AS350BA operations. Alternatively, for operations outside the safe limit for hydraulics OUT landing, the operational airworthiness authority may agree to accept the risk of hydraulics failure and consequent high probability of catastrophic results.

5.2. Specific Conclusions

5.2.1. The reduced control authority in the collective hydraulics OUT was unacceptable (see paragraph 4.1.2.1.b.).

5.2.2. The high forces in the collective control hydraulics OUT were unacceptable (see paragraph 4.1.2.3.a.).

5.2.3. The reduction in servo authority in cyclic control was unacceptable (see paragraph 4.1.3.2.).

5.2.4. The cyclic hydraulics OUT freeplay was unacceptable (see paragraph 4.1.3.4.a.).

5.2.5. The high forces in the longitudinal cyclic control axis hydraulics OUT were unacceptable (see paragraph 4.1.3.4.b.).

5.2.6. The high forces in the cyclic lateral control axis hydraulics OUT were unacceptable (see paragraph 4.1.3.4.c.).

5.2.7. The reduced tail rotor control authority in the hydraulics OUT mode was unacceptable (see paragraph 4.1.4.1.b.).

5.2.8. The pedal hydraulics OUT freeplay was unacceptable (see paragraph 4.1.4.3.a.)

5.2.9. The high forces in the tail rotor pedal control hydraulics OUT were unacceptable (see paragraph 4.1.4.3.b.).

5.2.10. Within the scope of the test, attempted landings hydraulics OUT at Referred Weights greater than 1950 kg were unacceptable (see paragraph 4.4.1).

5.2.11. The gust response of the aircraft below 1950 kg Referred Weight was unacceptable (see paragraph 4.2.4.).

5.2.12. The requirement for a hydraulics OUT hover landing at the completion of a maintenance test flight was unacceptable (see paragraph 4.5.3.a.).

5.2.13. The requirement to fly at 100 KIAS hydraulics out during maintenance test flights was unsatisfactory (see paragraph 4.5.3.b.).

5.2.14. The lack of a flight manual hydraulics out airspeed limit was unsatisfactory (see paragraph 4.5.1.a.).

5.2.15. As a result of data gathered during the testing, existing flight manual emergency procedures, limitations and flight characteristics explanations were unsatisfactory (see paragraph 4.5.1.b.).

5.2.16. In view of the trial results, the conduct of hydraulics OUT training operations was unsatisfactory (see paragraph 4.5.2.)

6. RECOMMENDATIONS

6.1. Recommendations - Essential Actions

6.1.1. The hydraulics system must be modified to ensure that collective control authority in the degraded mode is not reduced below acceptable limits or aircraft operations be restricted to ensure the control authority remains adequate in hydraulics OUT flight.

6.1.2. The high collective forces must be reduced to acceptable limits or a weight restriction be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration.

6.1.3. The hydraulics system must be modified to ensure that cyclic control authority in the hydraulics OUT mode is not reduced below acceptable limits or aircraft operations be restricted to ensure the control authority remains adequate in hydraulics OUT flight.

6.1.4. The hydraulics OUT longitudinal cyclic control forces must be reduced to acceptable limits or Referred Weight restriction and minimum airspeed of 15 Knots be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration.

6.1.5. The hydraulics OUT cyclic control forces must be reduced to acceptable limits or a Referred Weight restriction be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration and landings are only conducted into wind.

6.1.6. The hydraulics system must be modified to ensure that pedal control authority in the degraded mode is not reduced below acceptable limits or aircraft operations be restricted to ensure the control authority remains adequate in hydraulics OUT flight.

6.1.7. The hydraulics OUT pedal control forces must be reduced to acceptable limits or a weight restriction be placed on the aircraft to ensure that forces remain manageable for landing in the hydraulics OUT configuration.

6.1.8. The maximum Referred Weight for safe hydraulics OUT landings must be limited to 1950 kg.

6.1.9. The Flight Test Schedule must be amended to reflect the requirement to land with the minimum speed and other recommendations laid down in annex J.

6.1.10. The minimum approach speed hydraulics OUT must be increased in gusty conditions by half the gust factor to ensure that speed reduction into the area where an unacceptable reduction of handling qualities for landing does not occur.

6.2. Recommendations - Highly Desirable Actions

6.2.1. Reference N should be amended to reflect that the maximum airspeed for hydraulics OUT operations should be 70 KIAS. Accordingly, paragraph 410 and paragraph 10 of annex C to Section 4 of reference N should have 100 KIAS replaced with 70 KIAS.

6.2.2. The following statement should be inserted into section 5 of the current flight manual for the AS350BA (reference F):

Maximum airspeed for hydraulics out flight is 70 KIAS

6.2.3. Revised emergency procedures, limits and flight characteristics presented in annex K incorporating trial results should be included in the flight manual (reference F).

6.2.4. Revised training limitations detailed in annex K should be incorporated into AS350BA operators training guides.

7. REFERENCES

A. Formal Report - ARDU Task 0168 dated Jan 95.

B. Army LM Sqn Minute Army LMS/4080/A22/34 Pt 4 dated Mar 95.

C. DEFAIR DFS SIC KAB/KAE 008/DFS DTG 012320Z APR 97.

D. ADFHS UFO Section E Number 12.

E. Task Directive Task 0301 dated 11 Apr 97.

F. AAP 7210.014-1 AS350BA Flight Manual AL 2 dated Jun 96.

G. MIL-L-8501A: Helicopter Ground Handling and Flying Qualities dated 7 Nov 61.

H. MIL-F- 83300 Flying Qualities of Piloted V/STOL Aircraft dated 26 Sep 91.

I. Aeronautical Design Standard 33D - Handling Qualities Requirements for Military Rotorcraft dated July 1994.

J. Defence Standard 00-970 Vol 1 Rotorcraft dated 31 Jul 84.

K. Federal Aviation Regulation 27 Normal Category Helicopters dated January 1996.

L. Federal Aviation Regulation 29 Transport Category Helicopters dated January 1996.

M. ETPS Flight Test Manual dated Feb 95.

N. AAP 7210.014-6-15 AS350BA Flight Test Schedule AL 2 dated Dec 95.

O. The Referred Weight Flight Test Technique Applied to First of Class Flight Trials, A.M. Arney DSTO(AOD) DSTO-TR-0509.

P. Eurocopter Flight Manual AS350 BA Model dated 26 Nov 91.

8. TASK PERSONNEL

8.1. Task personnel were as follows:

a. TASKO: CAPT A.J. LANGLEY, BSc, QTP, AAVN 2 ARDU

b. Task Flight Test Engineer: FLTLT CP DANIEL, BEng (Elect), MSc(FD), FTE, MTTFLTCDR ARDU

c. Task Data Engineer: FLGOFF G.L. HAYES, BEng (Mech), MTT8 ARDU

DEFINITION OF TERMS

1. Table A-1 defines the terms used in the report's Conclusions and Recommendations.

Table A-1: Terms Used in Conclusions and Recommendations

DESCRIPTION OF DEFICIENCY	CONCLUSION	RECOMMENDATION TERMINOLOGY	RECOMMENDATION LEVEL
Prevents aircraft performing operational task or liable to cause accidents - restrictions needed to prevent occurrence are considered intolerable.	UNACCEPTABLE	Something must be done.	ESSENTIAL
Restricts aircraft's operational capability or is liable to cause accidents unless significant restrictions are imposed.	UNSATISFACTORY	Something should be done.	HIGHLY DESIRABLE
Should be improved to make a safer or more capable aircraft.	UNSATISFACTORY	Something should be done.	DESIRABLE
Satisfactory without improvement.	SATISFACTORY	No action.	No action.
Characteristic which improves the operational capability or safety of the design.	ENHANCING CHARACTERISTIC	Should be incorporated in future designs.	Desirable to incorporate in future designs.

2. Other terms which are used in the report are defined in the following paragraphs.

a. **Hydraulics OUT**. Hydraulics OUT is the term used to describe the degraded hydraulics mode ISOL or/and TEST or after a failure of the hydraulics system.

b. **Control Margin**. The Control Margin is the amount of control available to return from any point in the Permissible Flight Envelope to the appropriate Service Flight Envelope. With respect to landing, there should be sufficient Control Margin available in the critical sense in each channel to:

(1) reverse angular rate, and

(2) reverse angular rate resulting from critical system failure.

The nominal Control Margins which should be available are 5% for transient conditions and 10% for static conditions.

LIST OF ABBREVIATIONS AND SYMBOLS

Table B-1: List of Abbreviations and Symbols

ABBREVIATION OR SYMBOL	DEFINITION
'	Feet
σ	Relative Density
θ	Relative Temperature
δ	Relative Pressure
°	Degrees Celcius
°C	Degrees Celsius
$_0$	Subscript '0' refers to ISA condition
AAAvn	Australian Army Aviation
ADF	Australian Defence Force
ADFHS	Australian Defence Force Helicopter School
AFCS	Automatic Flight Control System
AOB	Angle Of Bank
ARDU	Aircraft Research and Development Unit
ASI	Airspeed Indicator
AUM	All Up Mass (analogous with AUW)
AUW	All Up Weight
BSc	Bachelor of Science Degree
CF	Control Force
CFT	Control Force Transient
CG	Centre of Gravity
CR	Control Reference
CRS	Control Reference System
DA	Density Altitude
DAS	Data Acquisition System
FAR	Federal Aviation Regulation
FCMC	Flight Control Mechanical Characteristics
fpm	feet per minute
ft	feet
FTE	Flight Test Engineer
fwd	Forward
GPS	Global Positioning System
H_p	Hectorpascal
HQR	Handling Qualities Rating (Cooper-Harper)
Hz	Hertz (Cycles per second)
IAW	In Accordance With
ISA	International Standard Atmosphere
ISOL	Hydraulics Isolate Mode
K	Kelvin
KCAS	Knots Calibrated Airspeed
kg	Kilograms
KIAS	Indicated Airspeed
lb	pounds
LSTFCP	Low Speed Trim Flight Control Position
min	Minute
mm	Millimetres
MSc	Master of Science
N_G	Gas Generator Speed
N_R	Mainrotor Speed
OAT	Outside Air Temperature
OC	Officer Commanding

ABBREVIATION OR SYMBOL	DEFINITION
°C	Degrees Celsius
P	Pressure
Posn	Position
PSI	Pounds Per Square Inch
QTP	Qualified Test Pilot
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RAN	Royal Australian Navy
ROD	Rate Of Descent
RW	Referred Weight
SAA	School of Army Aviation
SAR	Search and Rescue
SFR	Servo Forward Reference
SHOL	Ship-Helicopter Operating Limits
SLR	Servo Lateral Reference
SR	Servo Reference
STR	Servo Tail Reference
T	Temperature
TFCP	Trim Flight Control Position
USAF	United States Air Force
VMC	Visual Meteorological Conditions
V_{NE}	Never Exceed Speed

HYDRAULIC SYSTEM AND FLIGHT CONTROLS

Flight Controls

1. **General.** The AS350BA Squirrel was fitted with dual conventional flying controls in a side by side cockpit arrangement. The control reference system is presented at Table 1. Control of the semi-rigid main rotor was made through a simplex hydraulic system with 1 fore-aft servo and 2 roll servos mounted on the main gearbox. Control of the tail rotor was made through a simplex, hydraulically actuated tail rotor servo mounted just aft of the tail boom attachment point. The mechanical flight control system included a conventional cyclic pitch control stick, collective pitch lever and tail rotor pitch control pedals. The aircraft was also fitted a cyclic stick feel system. A cyclic trim system and an autopilot were fitted to Navy aircraft, however these were not installed on the test aircraft and will not be described in this Annex. A diagram of the flying controls is presented at Figure C-1.

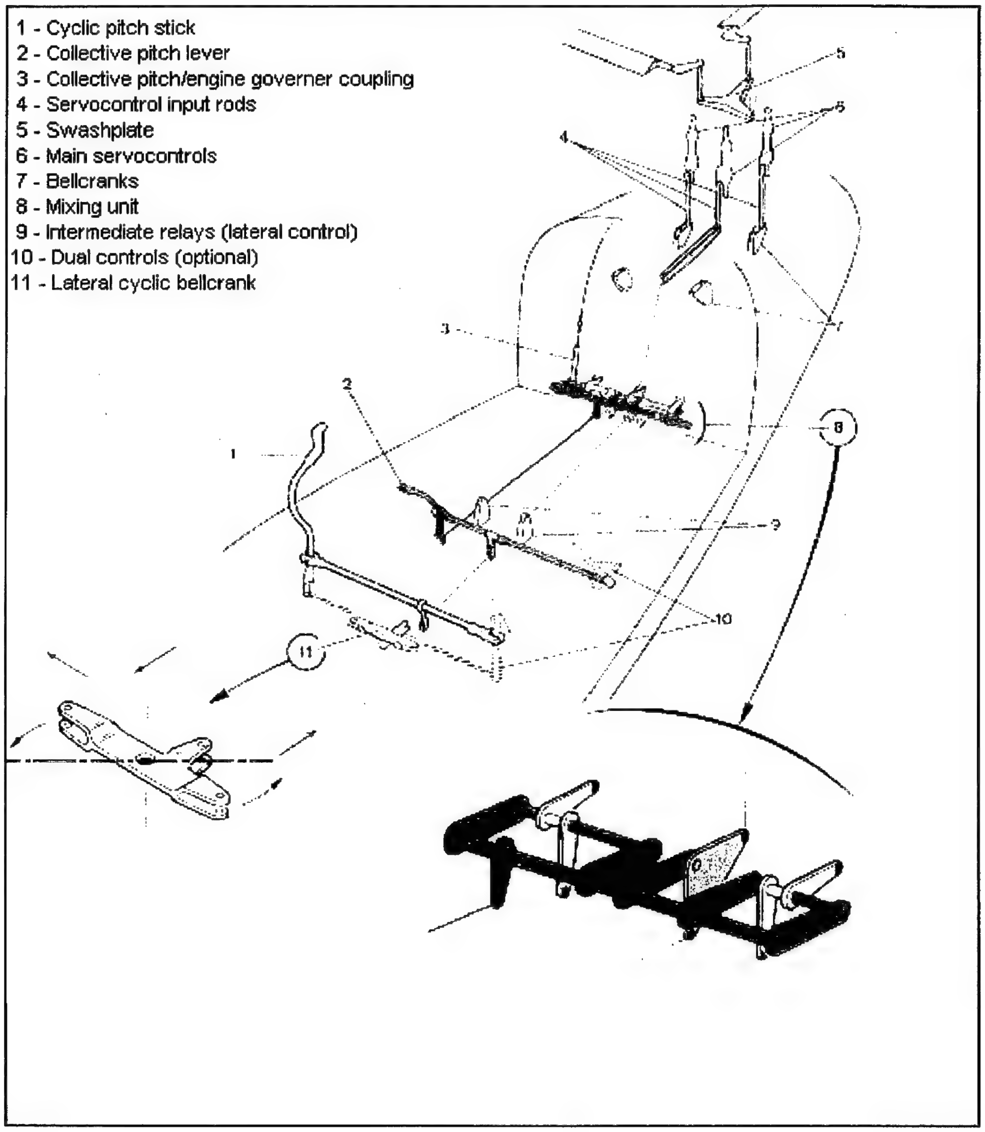


Figure C-1: AS350BA Flying Controls

2. **Cyclic and Collective.** Cyclic and collective movements were transmitted via rigid control rods through a mixing unit which translated the control inputs into servo commands and was designed to facilitate cyclic and collective lever movement without interaction. The servos moved the main rotor swashplate which altered the main rotor blade pitch via the pitch change rods. The collective control run contained an interlink (collective pitch to yaw coupling) which altered tail rotor pitch, and was designed to compensate for changes in collective pitch. A hydraulic servo system was designed to produce near zero flight control loads for the pilot. All aircraft were fitted with attachment points for the SFIM AFCS 85-T31 autopilot, however only aircraft with tail numbers of 020 and higher (previously used for RAAF SAR roles) had them fitted. Within the fixed parts of the autopilot fitted to all airframes, an artificial load system (magnetic brake and spring) on the cyclic control permitted the cyclic control to be trimmed in any position.

3. The control linkages between the cyclic stick, collective lever and swashplate consisted of rigid control rods interconnected by bellcranks and levers (refer Figure C-2). A mixing unit constituted the cyclic/collective control interface and allowed these two controls to operate through the same set of servos.

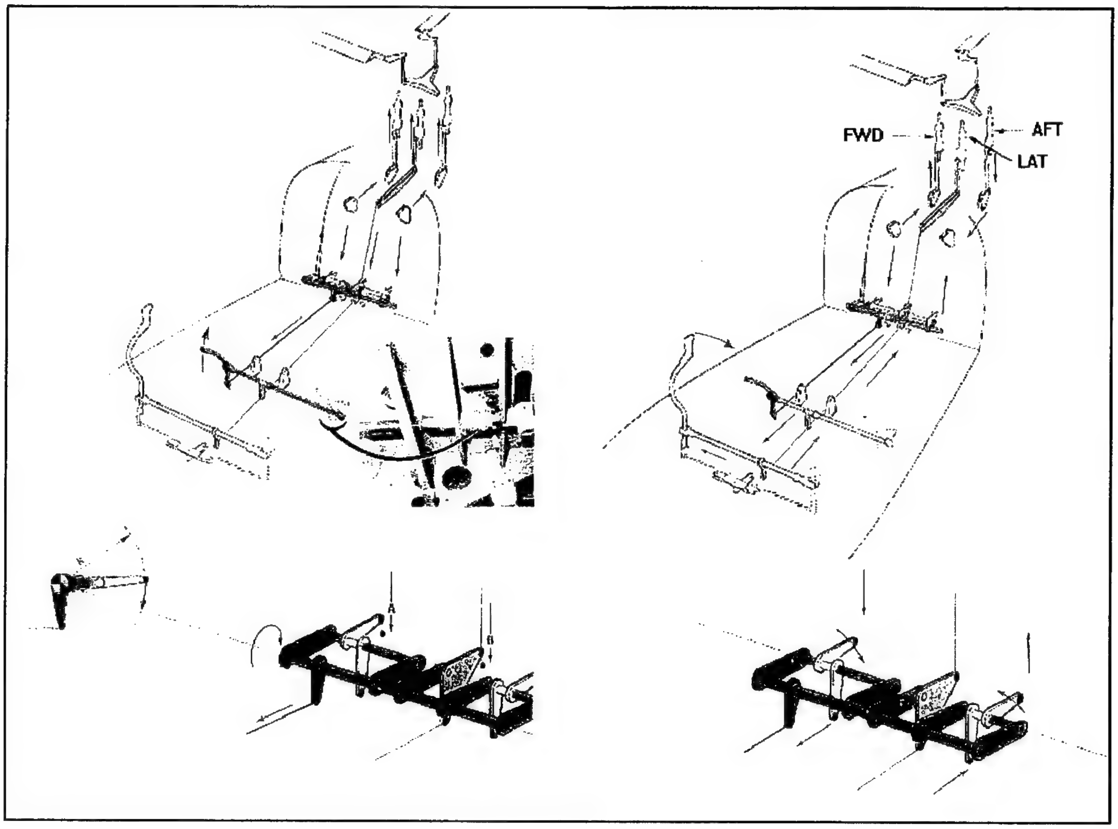


Figure C-2: Collective and Cyclic Control Linkages

4. **Pedals.** Movement of the yaw pedals was transmitted to the tail rotor servo by a system of rigid rods and ball-type control cables. The tail rotor servo was mounted in the tail boom and moved a rod which actuated the tail rotor plate bellcrank. The bellcrank adjusted the tail rotor pitch angle. The yaw pedal position was adjustable by interchanging the pedals, fully forward or fully aft and required the removal of a locating pin to reverse the pedals. Tail rotor controls consisted of bellcranks, pushrods, cables and pulleys which actuated the hydraulic servos to change the pitch of the tail rotor blades. The tail rotor control pedals were interconnected by a rocker arm so that when one pedal moved forward the other moved backward. The tail rotor control system is shown at Figure C-3.

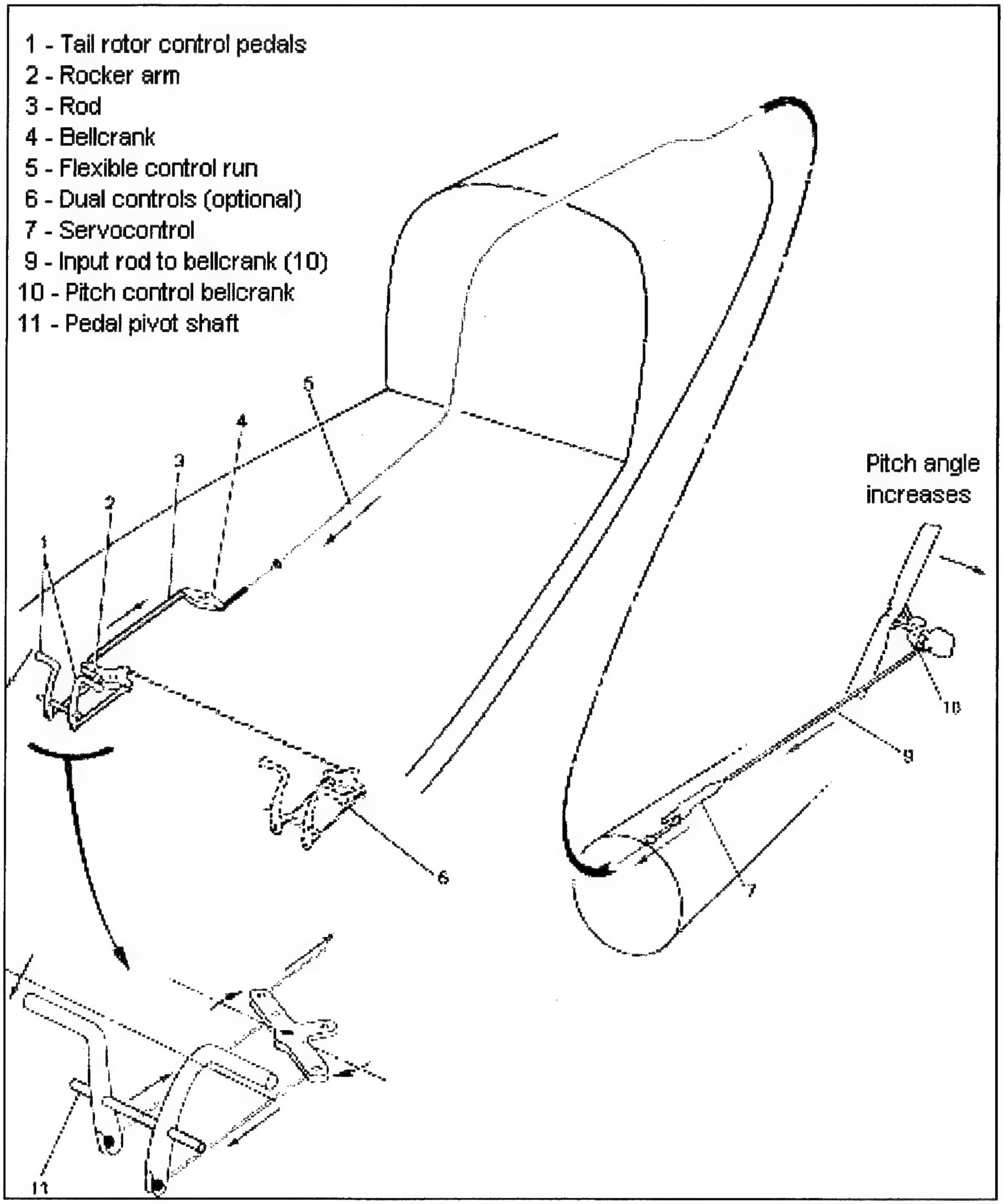


Figure C-3: Tail Rotor Control Linkages

5. All ADF AS350BA aircraft had a collective-yaw mechanical coupling as shown in Figure C-4. As the yaw channel had no trim actuator, balance had to be maintained by the pilot by varying the tail rotor pedal position for large changes in power or airspeed. To avoid requirement for pilot input for small variations in power and airspeed, a collective-yaw coupling was introduced in the tail rotor circuit. The designed effective authority was 24%. For small collective changes, the balance task was designed to be absorbed by the coupling. The collective-yaw coupling was installed as part of the fixed parts of the autopilot installation. Coupling with the collective pitch was obtained by the collective bellcrank that pivoted on a bellcrank secured to a torque shaft. This shaft was connected to the collective pitch bellcrank by a spring rod which allowed collective lever operation if the yaw control seized.

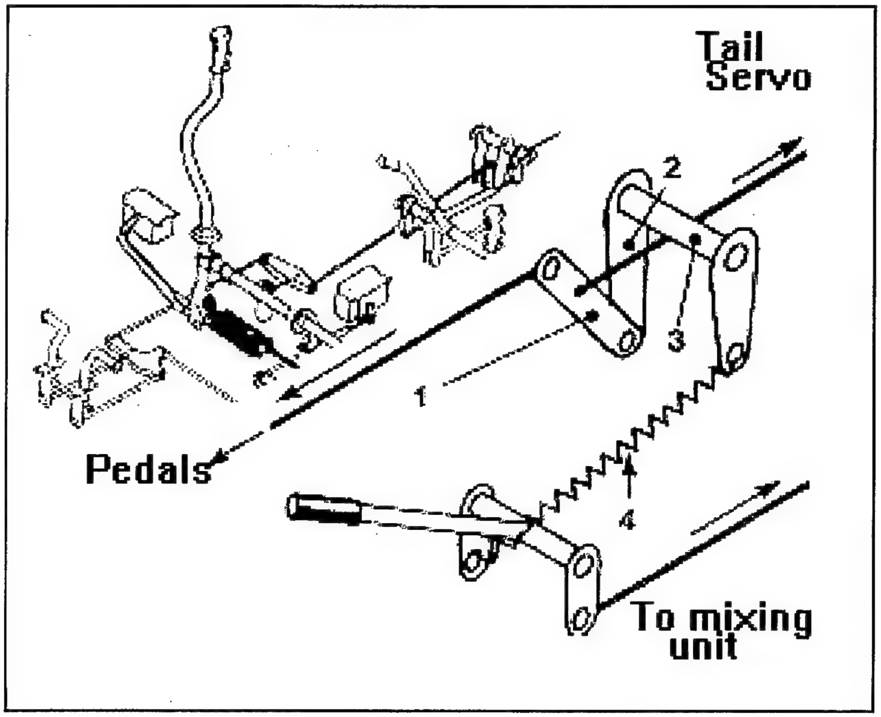
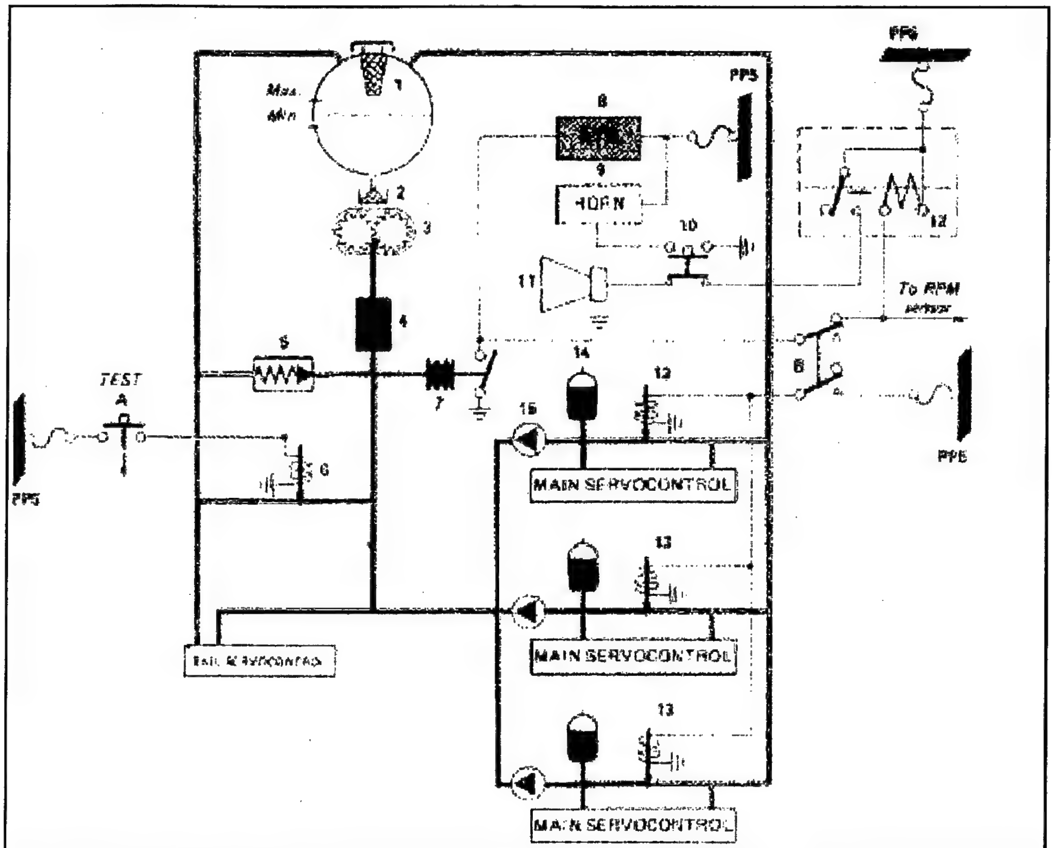


Figure C-4: Collective-Yaw Mechanical Coupling

Hydraulic System

6. **Principle of Operation.** A single hydraulic servo system (Figure C-5) supplied power to reduce the forces required on all flight controls. Hydraulic oil was drawn from a reservoir by a pump driven by the engine main gearbox coupling and was then supplied via a filter to three main rotor and single tail rotor servos. The main servos were fitted with limited capacity accumulators which provided emergency hydraulic pressure (15 bar) for a short time if pressure was lost in flight. Movement of a pilot's flight control moved a spool valve (in the hydraulic servo) which directed hydraulic fluid under pressure to either side of the servo piston. The piston was fixed and the servo body moved the appropriate control.



1	Hydraulic Reservoir	9	Horn Advisory Light
2	Magnetic Plug	10	Enable/Disable Horn Switch
3	Hydraulic Pump	11	Horn
4	10 micron Mesh Filter	12	Horn Control Relay
5	Pressure Regulating Valve	13	HYD Isolate Solenoids
6	Hydraulic Test Valve	14	Hydraulic Servo Accumulators
7	Low Pressure Indicator Switch.	15	Non Return Valve
8	HYD Caption (Caution Light)	A	Hydraulic Test Switch
		B	Hydraulic Isolate Switch

Figure C-5: AS350BA Hydraulic System

7. **Hydraulic Servocontrol.** Dunlop type servocontrols were installed on the ADF AS350BA helicopters. The servocontrols were of the single cylinder type. The swashplate servocontrol piston was anchored on the main rotor shaft housing (on the Main Gearbox) and to the swashplate (refer Figure C-6). The tail rotor servocontrol was anchored to the structure by means of an identical rod end fitting. The output motion of each servocontrol was coupled to the input control movements. The servocontrol moved the servo body via an actuator which ported the hydraulic fluid under pressure from one side of the piston in the servocontrol (attached to the airframe) to the other. This in turn moved the output side of the control linkage through direct connection to the servo body. Feedback loads to the actuator output side were not transmitted under design flight conditions (see paragraph 11).

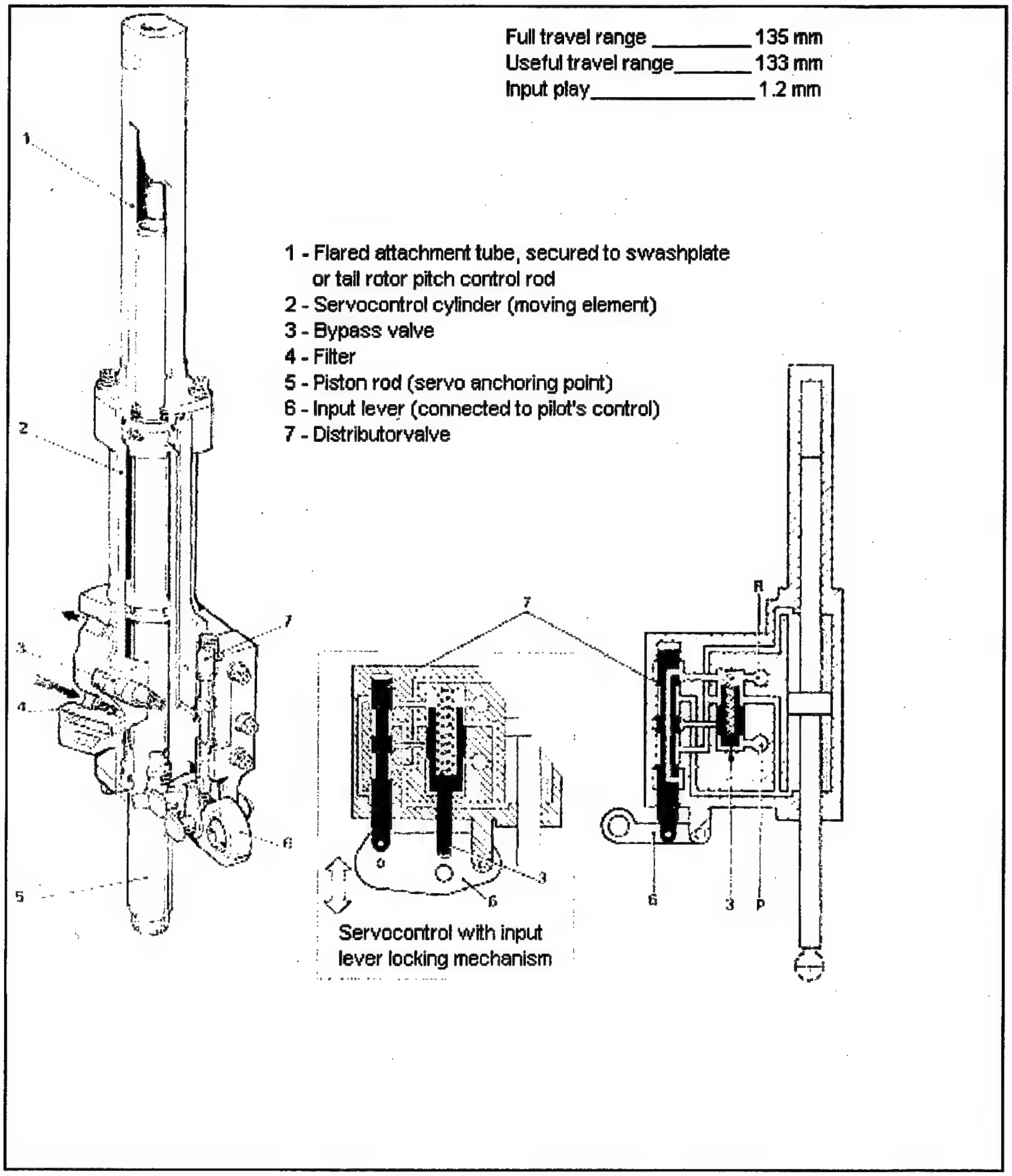


Figure C-6: Hydraulic Servo Control

8. **Hydraulic Servo Accumulators.** Limited capacity accumulators were installed on each main rotor servo on the main gear box. When system pressure was lost, correctly charged accumulators allowed sufficient residual pressure to enable the pilot to decelerate the aircraft to an airspeed where aerodynamic feedback forces were manageable.

9. **Hydraulic Isolate Switch.** A guarded, two-position 'HYDRAULIC ISOLATE' switch was located on the pilot's collective lever head. In the normal (de-activated) position, the main servo solenoid valves act to eliminate any residual pressure on the servo control pistons and thereby reduce the mechanical loads required to move the control linkage. When the switch was activated, solenoid valves on each of the main rotor servos were lifted causing servo accumulator pressure to be dumped and hydraulic fluid bypass of the servo piston. In this way accumulator pressure could be dumped uniformly, equalising cyclic control loads in each of the servo actuation directions preventing control difficulties which could occur due to hydraulic assistance being available in one cylic direction but not others. Ground tests conducted at

ARDU revealed that a residual pressure of 150 PSI existed in the ISOL Mode. The residual pressure was also observed in flight via reduced pedal forces when compared to the TEST mode.

10. **Hydraulic Test System.** The hydraulic low pressure warning system and the capacity of the main servo accumulators was checked prior to flight by activating a 'HYD TEST' switch. The switch was also used during aircrew training to simulate aircraft hydraulic malfunction. The switch activated a solenoid valve which opened the pressure line to the reservoir return. This flow was unrestricted and the system pressure dropped to zero. All warning systems activated simultaneously, as well as increased control force on the tail rotor pedals. Main servo pressure remained until the accumulator pressure was depleted (approximately 8 cycles of the cyclic through 10% of the control range).

11. **Jack Stall.** The aircraft's hydraulic system operating pressure was relatively low. The system was capable of providing hydraulic boost to the flight controls under most flight conditions. However, at a high positive 'G', main rotor aerodynamic loads increased to a point where the hydraulic servos were unable to relieve control feedback forces to the pilot. A reduction in the severity of the manoeuvre eliminated the jack stall.

12. **Failure modes.** During hydraulics OUT operation the following changes were observed within the hydraulics system. With a loss of hydraulic pressure the bypass valve in the servocontrol was retracted under the effect of a spring and the two actuator chambers were interconnected. The pilot's control inputs, transferred via control rods, moved the actuator lever arm until it beared against the mechanical stops on the servocontrol body. The pilot's input then moved the control surface. Consequently, movement of the lever arm between the two mechanical stops, combined with freeplay in the control runs, manifested itself as system freeplay. Movement of the servocontrol after loss of hydraulic pressure is depicted in Figure C-7. This freeplay was not evident in the hydraulics ON mode.

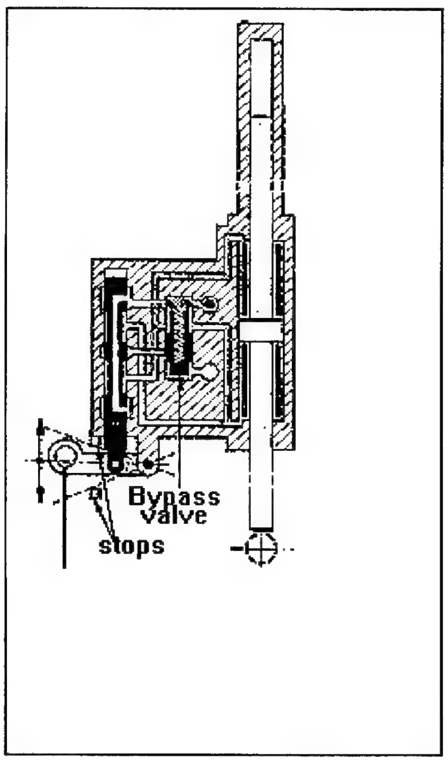


Figure C-7: Control Movement during Hydraulics Failure

Control Reference System

13. **Control Reference Points (CR Points).** Flight control displacement data was taken from the right hand side pilot's station. The control reference points (CR points) from which measurements were taken are described as follows:

a. **Cyclic CR Point.** The longitudinal cyclic CR point was the position at which the pilot's index finger was in contact with the forward face of the cyclic stick grip and coincided with the upper point of the ICS/Radio trigger switch.

b. **Collective CR Point.** The collective CR point was the lower rear left extremity of the collective electrical switch housing.

c. **Yaw Pedal CR Point.** The yaw pedal CR point was the top left corner of the right yaw pedal.

14. **Control Reference Positions (CR Posns).** Control displacements were measured from the CR Points. The CR Posns were established using fixed points in the right hand pilot's station.

a. **Cyclic Stick.** The longitudinal position of the cyclic CR Posn was measured from the cyclic CR Point to the front face of the HSI course select knob. The lateral position was measured from the cyclic CR Point to the front face of the third lowest windscreen retaining nut on the cabin door support frame, 7 cm above the bottom corner of the right rear of the pilot's window. The cyclic CR positions are shown at Figure C-8.

b. **Collective Lever.** The position of the collective CR Posn was the forward right hand lower point on the rotor brake and fuel shut off housing. The collective CR Posns are presented at Figure C-9.

c. **Yaw Pedals.** The yaw pedal CR Posn was taken with the pedals in a level position, installed in the fully forward configuration. The CR Point was the extreme forward face of the cyclic uniball where it contacted the floor. The CR Posn and CR Point are shown at Figure C-10.

15. **Control Reference System (CRS).** The CRS used represented full displacements of the all controls from the CR Posns. The CRS is presented at Table C-1.

<table>
<tr><th>Serial
(a)</th><th>Control
(b)</th><th>Position
(c)</th><th colspan="2">Indicated Displacement On Instrumentation (mm)
(d)</th><th colspan="2">Indicated Displacement On Instrumentation (%)
(e)</th></tr>
<tr><td>1</td><td>Longitudinal Cyclic</td><td>Forward
CR Posn
Aft</td><td colspan="2">35.0
62.65
90.3</td><td colspan="2">0.0
50.0
100.0</td></tr>
<tr><td>2</td><td>Lateral Cyclic</td><td>Left
CR Posn
Right</td><td colspan="2">62.0
84.0
106.0</td><td colspan="2">0.0
50.0
100.0</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Yaw Pedals</td><td></td><td>Collective Down</td><td>Collective Up</td><td>Collective Down</td><td>Collective Up</td></tr>
<tr><td>Right Pedal Aft
CR Posn
Right Pedal Fwd</td><td>1.9
48.5
95.2</td><td>2.2
47.5
92.9</td><td>0.0
50.0
100.0</td><td>0.3
48.9
97.6</td></tr>
<tr><td>4</td><td>Collective</td><td>Locked Down
Max Pitch Stop</td><td colspan="2">16.5
74.7</td><td colspan="2">0.0
100.0</td></tr>
</table>

Table C-1 - Control Reference System Measurements

Servo Reference System

16. Servo control displacement data was measured by transducers connected in parallel with each hydraulic servo. Data was taken with the hydraulics system selected ON, ISOL and TEST. Servos on the main transmission were identified by referring to them as a position on the transmission with reference to the aircraft axis. Measurements (Table C-2) were taken at the servos over their full range with the cockpit controls in the following positions:

a. **Forward Servo (Servo Fwd).** The Servo Fwd was measured from the fully down position which corresponded to the collective fully down with the cyclic in the forward right extremity, to the fully up position which corresponded to collective fully up and the cyclic positioned aft and left. The Servo Fwd Reference Position (SFRPosn) was the servo position at which the cyclic and collective were at their respective CR Posns.

b. **Lateral Servo (Servo Lat).** The Servo Lat was measured from the fully down position which corresponded to the collective fully down with the cyclic in the aft and right extremity, to the fully up position which corresponded to collective fully up and the cyclic positioned forward and left. The SLRPosn was the servo position at which the cyclic and collective were at their respective CR Posns.

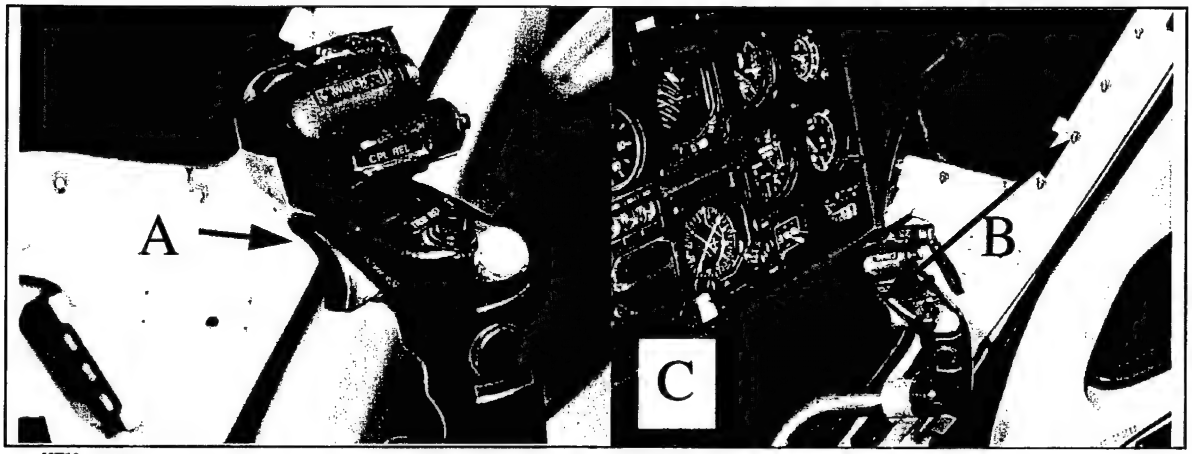
c. **Aft Servo (Servo Aft).** The Servo Aft was measured from the fully down position which corresponded to the collective fully down with the cyclic in the forward left extremity, to the fully up position which corresponded to collective fully up and the cyclic positioned aft and right. The SARPosn was the servo position at which the cyclic and collective were at their respective CR Posns.

d. **Tail Rotor Servo (Servo Tail).** The Servo Tail was measured from the fully retracted position which corresponded to right pedal fully aft, to the fully extended position which corresponded right pedal fully forward. The STRPosn was the servo position at which the right pedal was in its respective CR Posn.

Serial (a)	Servo (b)	Position (c)	Indicated Displacement On Instrumentation (mm) (d)	Indicated Displacement On Instrumentation (%) (e)
1	Forward	Down SFRPosn Up	2.7 42.9 117.8	0 35 100
2	Lateral	Down SLRPosn Up	6.9 29.2 89.6	0 27 100
3	Aft	Down SFRPosn Up	3.3 21.5 86.2	0 22 100
4	Tail	Right Pedal Aft CR Posn Right Pedal Fwd	4.8 21.5 88.4	0 20 100

Table C-2 - Servo Control Reference System Measurements

COMMON DATA		
Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: CR Position orientated forward
Tailnumber: A22-009	Location: Inside Hangar	Cyclic Stick: CR Position
Date of Test: 20 May 97	Engines and Rotors Stopped	Collective: CR Position
Aircraft Hours: 4502.5	External Hydraulic & Electric Power Connected	Seat Fully Forward



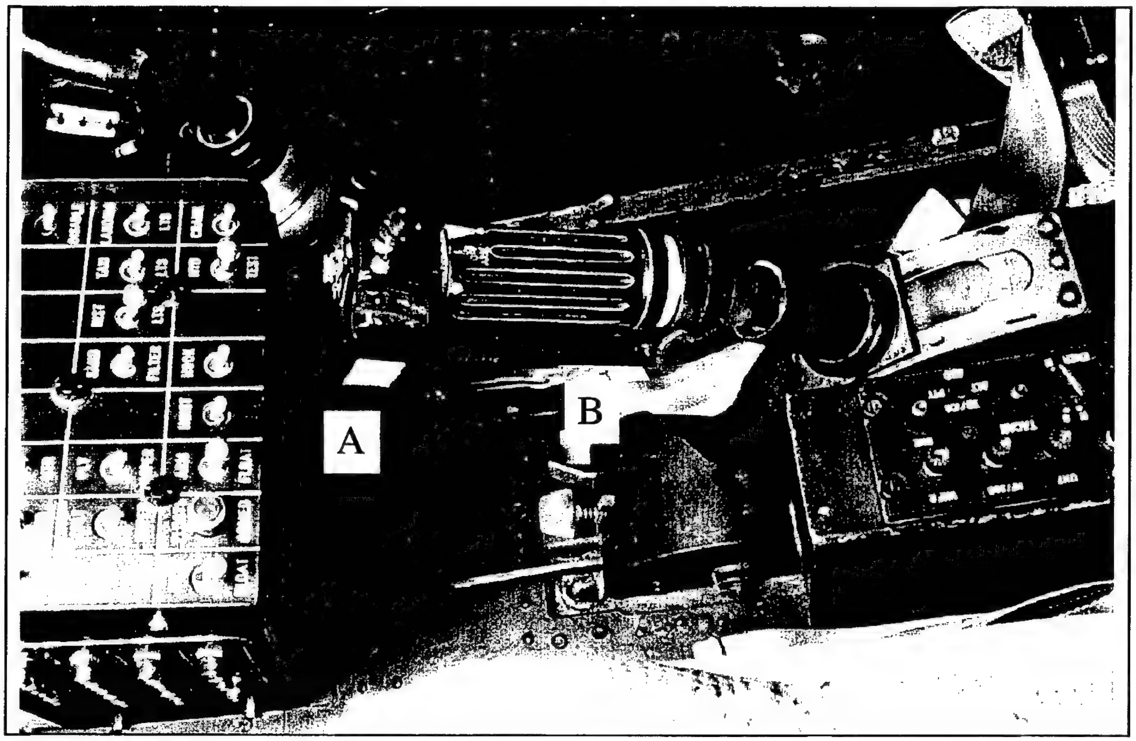
KEY

Description		Distance
A	Cyclic CR Point	-
B	Cyclic Lateral Control Reference Position (distance from the CR Point)	433 mm
C	Cyclic Longitudinal Control Reference Position (distance from the CR Point)	154 mm

Figure C-8: Cyclic CR Points and CR Posns

COMMON DATA

Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: CR Position installed in forward position
Tailnumber: A22-009	Location: Inside Hangar	Cyclic Stick: CR Position
Date of Test: 20 May 97	Engines and Rotors Stopped	Collective: CR Position
Aircraft Hours: 4502.5	External Hydraulic & Electric Power Connected	Seat Fully Forward

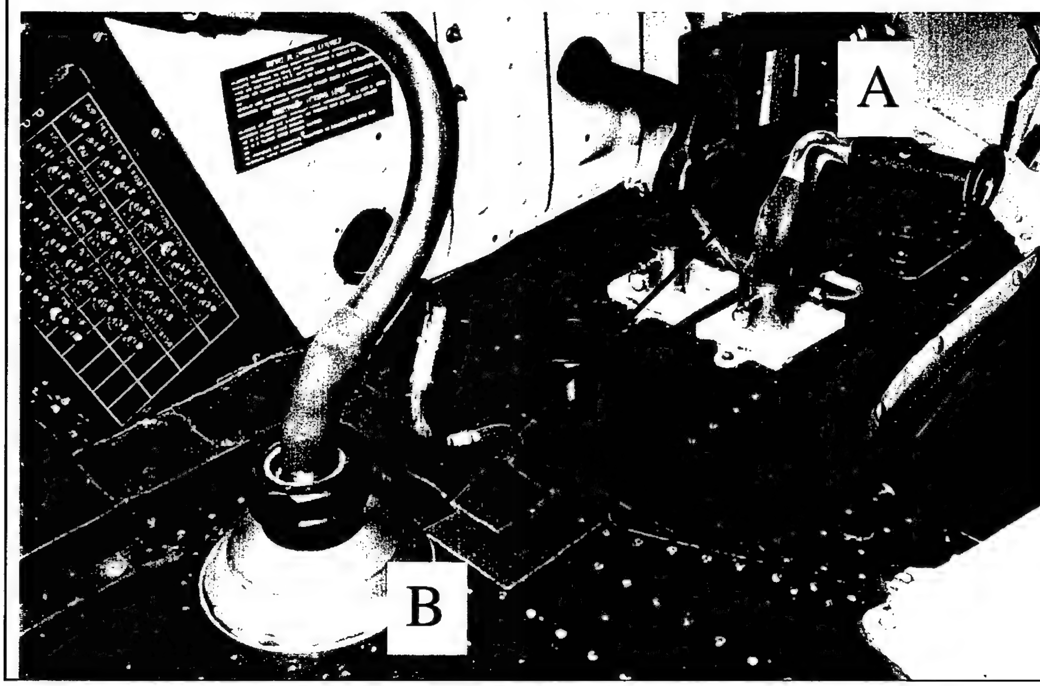


KEY

Description		Distance
A	Collective Control Reference Point	-
B	Collective Control Reference Position (distance to CR Point)	228 mm

Figure C-9: Collective CR Posn and CR Point

COMMON DATA		
Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: CR Position installed in forward position
Tailnumber: A22-009	Location: Inside Hangar	Cyclic Stick: CR Position
Date of Test: 20 May 97	Engines and Rotors Stopped	Collective: CR Position
Aircraft Hours: 4502.5	External Hydraulic & Electric Power Connected	Seat Fully Forward



KEY

Description		Distance
A	Pedals Control Reference Point (upper left corner of pedal)	-
B	Pedals Control Reference Position distance from the CR Point	434 mm

Figure C-10 - Pedal CR Points and CR Posns

INSTRUMENTATION AND DATA REDUCTION

INSTRUMENTATION

1. **General.** The instrumentation for the AS350BA Squirrel Helicopter recorded the control forces and positions, tail rotor and swashplate servo positions, aircraft velocities, height and heading. These measurands were obtained by means of an instrumentation system comprising of sensors, a computer based data acquisition system (DAS), and GPS system. All sensor measurands, excluding aircraft velocity, were automatically recorded by the DAS at a rate of 10 Hz. Aircraft velocity was recorded using a GPS data logger. The instrumentation suite was fixed to the rear cabin floor. Two small metal trunks, loaded with variable amounts of weight, were lashed to the rear cabin floor to provide the CG and AUW variations required for the flight test program. Figures D-1 to D-4 show the DAS, and typical force and position transducer installations.

2. **Collective, Cyclic and Pedal Force Sensors.** The forces (bending moments) were obtained by mounting 1 000 ohm strain gauges in a typical bending bridge configuration above the friction nut of the collective control stick, at the base of the cyclic control stick and at the base of each pedal.

3. **Collective, Cyclic and Pedal Position Sensors.** The collective control, cyclic lateral and longitudinal, and pedal control positions were obtained using linear resistive displacement sensors.

4. **Swashplate Servo Position Sensors.** The forward, aft and lateral swashplate servo positions were obtained using linear resistive displacement sensors. Each sensor was fixed between the actuator and the lower actuator securing attachment point.

5. **Tail Rotor Position Sensor.** The tail rotor pitch servo position was obtained using a linear resistive displacement sensor. The sensor was fixed just aft of the tail rotor actuator.

6. **Event Marking.** Provision for event marking the data being logged by the laptop computer (eg start and finish of each manoeuvre) was provided by means of an aircraft press to talk switch clipped to the FTE's knee pad. One side of the switch was connected to the power supply and the other to a DAS input line. Because the Event Number was not displayed to the flight test crew, GPS time, to which the DAS's internal clock was synchronised, was also recorded for each manoeuvre to ensure that the test event could be tracked during post flight data processing.

7. **Data Acquisition System.** The data acquisition system was based around a NEC Versa laptop computer fitted with a National Instruments DAQ700 data acquisition card. The card was installed into the PCMCIA slot of the laptop computer, its analog input lines were used to monitor the outputs of the sensors, and one of its digital input lines to monitor the event mark switch. The DAS, ancillary instrumentation and power supply were enclosed in a purpose built aluminium box. The box was secured via anti vibration mounts to a plywood sheet in the rear passenger area using tie down straps and turnbuckles to existing hard points.

8. **GPS System.** The GPS system was required to give ground speed information which could be correlated to stick forces and manoeuvres. The GISMO GPS was connected to an external GPS antenna mounted on the top engine cowling. The GPS was powered using 12 volt Panasonic NICAD batteries. The GPS was mounted on the aluminium box housing the DAS.

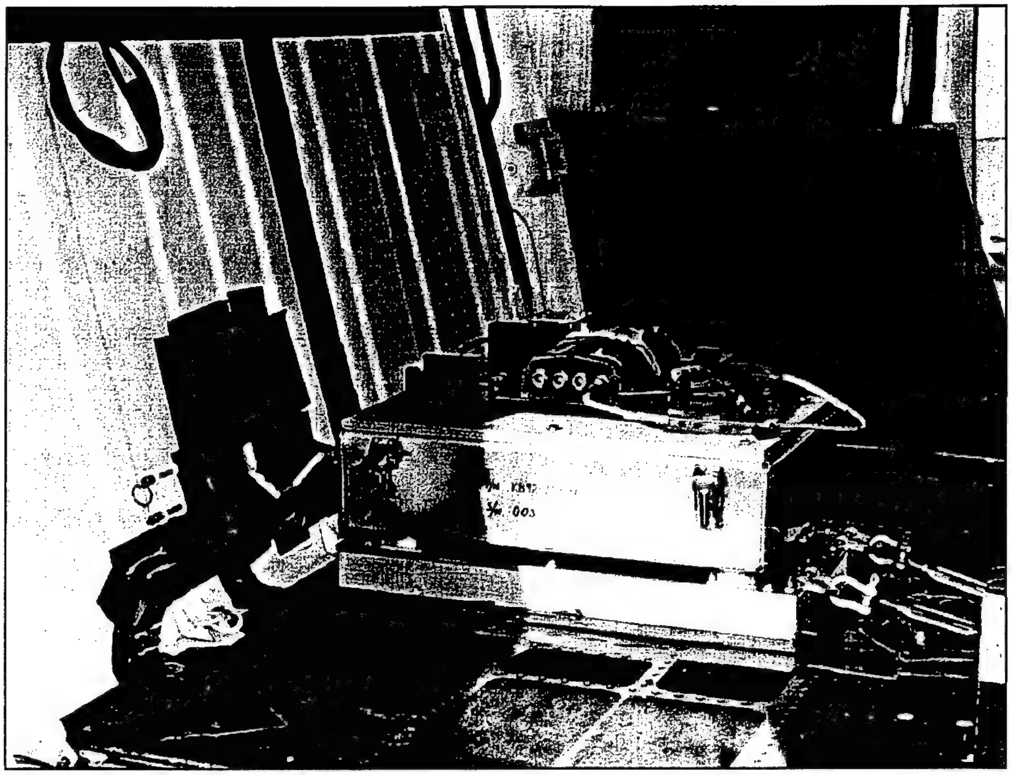


Figure D-1: DAS Installation

Figure D-2: Cyclic Force Transducer

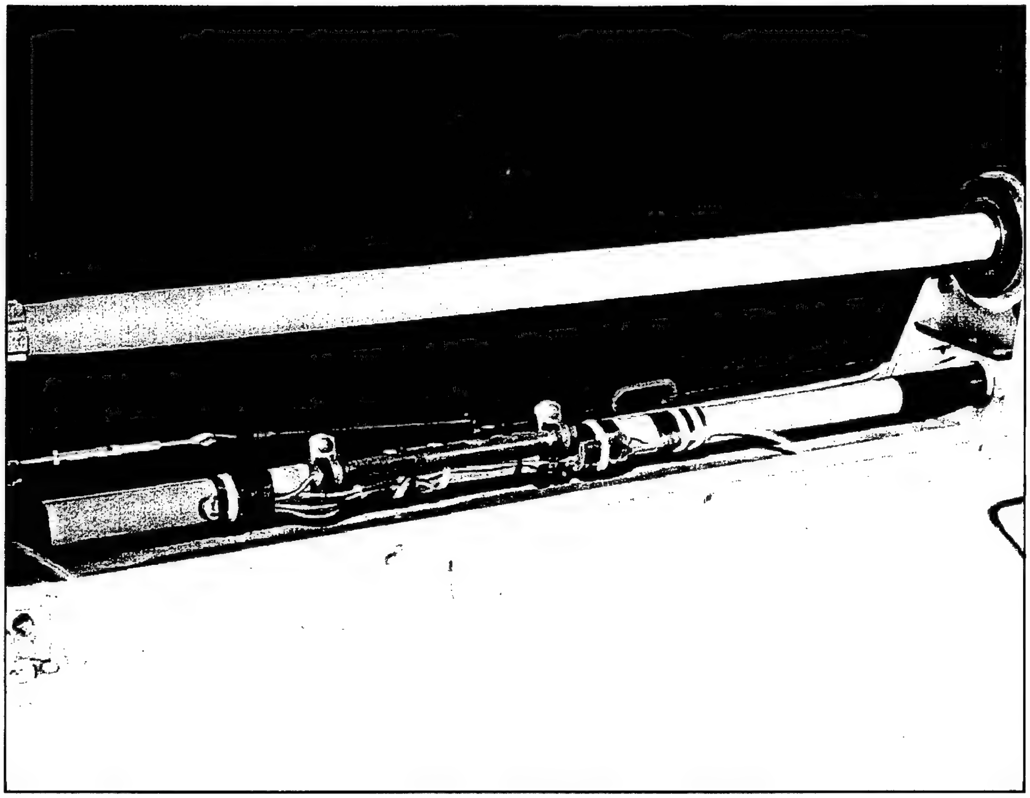


Figure D-3: Tail rotor Servo Position Transducer

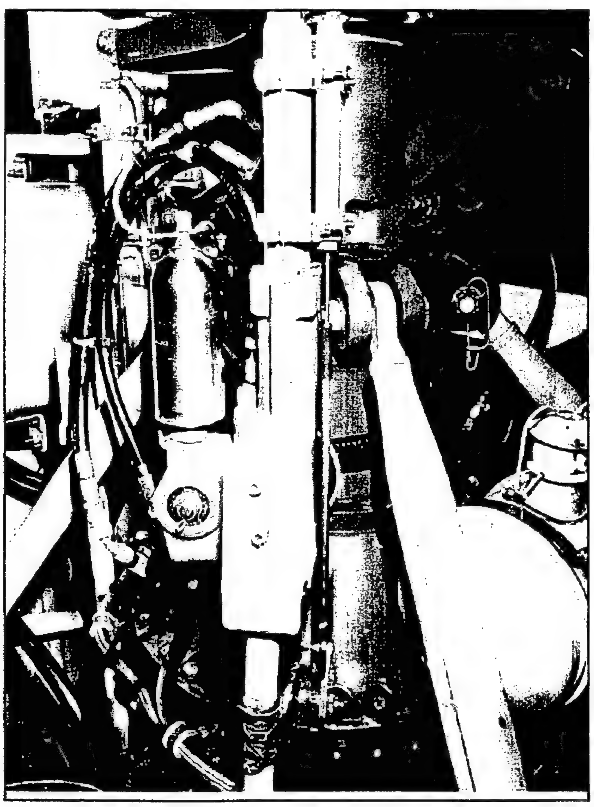


Figure D-4: Main Rotor Servo Position Transducer

9. **Measurement Accuracies**. The accuracies of the DAS measurands are detailed in Table D-1.

Serial (a)	Measurement (b)	Equipment (c)	Units (d)	Accuracy (e)
1	Control Positions	Transducers	mm	±1.3
2	Servo Positions	Transducers	mm	±1.3
3	Control Forces	Strain Gauges	lbF	±2.8
4	Ground Speed	C/A Code GPS	kts	±1.0
5	Synchronised GPS/DAS Time	Computer / C/A Code GPS	sec	±1.0
6	Manualy Recorded Event Timel	C/A Code GPS	sec	±3.0

Table D-1: Measurand Accuracies

10. **DAS Software.** The operation of the DAQ700 card were controlled by a software program written using National Instruments Labview software (Version 3.0). Labview was a graphical programming language for data acquisition and control applications. The software program sampled the output voltage of the sensors from the DAQ700 card, performed engineering unit conversions, saved the data to the computer's hard drive, and displayed the current value of each measurement onto the computer's screen for testing and calibration purposes. In addition, the software monitored the logic state of the event mark switch and tagged the logged data each time it was pressed.

11. The software program consisted of five software modules, called Virtual Instruments (VIs) and are as follows:

a. Squirrel Hydraulics VI. This top level VI samples the output voltage of the sensors from the DAQCard-700, performs engineering unit conversions, displays and saves the current time, measurands data and event counter to the computer's screen and hard drive respectively.

b. Event VI. This sub VI counts the number of times the event mark switch was pressed.

c. Acquire Time VI. This sub VI acquires the current time from the computer's internal clock.

d. Data Processing. This sub VI removes the effects of electrical noise from the sampled output voltages of each sensor acquired by the DAQCard-700, and converts the data to the appropriate engineering units.

e. Log Data VI. This sub VI stores the current time, measurand data, and event counter number to the data file designated by the operator.

12. **Manual Recording**. All qualitative HQR ratings and comments during test events were manually recorded on the test cards by the FTE.

DATA REDUCTION

13. DAS data was reduced using SigmaPlot® 4.0. SigmaPlot® 4.0 was a technical graphing program which could easily manipulate and graph 36 000 lines (average amount for a one hour sortie) of data. Irrelevant data recorded between the test events was manually deleted using the Event Number and GPS time as a reference. Microsoft® Excel Version 5.0 was used to a lesser extent to graph reduced FCMC data. Excel could not be used for the DAS data reduction due to its limitation on file size (max 16 000 lines).

14. An RS1™ program was used to interpolate the GPS data and time synchronise it with the DAS data.

TEST AIRCRAFT AND AIRCREW DETAILS

1. **Aerodynamic Condition.** The AS350BA tested, serial number A22-009, was a modified aircraft in the clean configuration (no role equipment was fitted) which had instrumentation for the trial specifcally installed. The aircraft was in good aerodynamic condition with a standard ADFHS white gloss external finish.

2. **Airframe and Engine Hours**. Details of the airframe and engine hours at the start of the tests are at Table E-1:

Serial (a)	Item (b)	Details (c)
1	Airframe	4489.9 AFHRS
2	Engine	2937.7 AFHRS
3	Comp Wash	3 Feb 97 - 4398.0 AFHRS

Table E-1: Airframe And Engine Hours

3. **Modification State**. The aircraft modification state is detailed in Appendix 1 to this Annex.

4. **Seating Position.** The assessing pilot's seat was adjusted to the fully forward and the pedals were installed fully forward. The Flight Test Engineer was fully strapped in the left seat, positioned fully aft, for the duration of the testing.

5. **Flying Clothing.** The flying clothing worn by the assessing pilot and engineer is detailed in Table E-2:

Serial (a)	Item (b)	Details (c)
1	Boots	RAAF Standard Aricrew Issue
2	Coverall	ADA Standard Olive Green
3	Gloves	Nomex/Leather Standard
4	Helmet	Alpha 207

Table E-2: Flying Clothing

6. **Test Aircrew.** The assessing pilot, Capt A.J.Langley, had a total of 2410 flight hours. The assessing engineer, FLTLT C.P.Daniel, had a total of 80.4 flight test hours. Their relevant experience is summarized in Tables E-3 and E-4 respectively.

Serial (a)	Aircraft (b)	Role (c)	Hours (d)
1	CT4-A	Training	75
2	BELL 206 B-1	Reconnaissance	1515
3	S 70 A-9	Utility/Troop Lift	165
4	Various Rotary Wing Types	Test Flying	655

Table E-3: Test Pilot Experience

Serial (a)	Aircraft (b)	Role (c)	Hours (d)
1	PC-9/A	Training	63.7
2	F/A-18	Fighter	13.2
3	Other	Test Flying	3.5

Table E-4: Flight Test Engineer Experience

7. The relevant percentiles of the assessing pilot, based on the Anthropometric Survey of 2000 RAF aircrew 1970/71, are presented in Table E-5:

Serial (a)	Item (b)	Size (c)	Units (d)	Percentile (e)
1	Height	1734	mm	28%
2	Sitting Height	938	mm	56%
3	Thigh Length	595	mm	30%
4	Leg Length	1034	mm	15%
5	Functional Reach	792	mm	40%
6	Weight	70	kgf	39%

Table E-5 - Pilot Percentiles

MODIFICATIONS INCORPORATED IN AIRCRAFT A22-009

Modifications 7210.014-XXX

Serial (a)	Mod No (b)	Title (c)
1	101	Fitment of Additional Skid Tube Wear Plates
2	104	Additional Front Door Internal Handle
3	105	Fitment of Electronic Filter Module
4	106	Replacement of Roll Pins by Monel Rivets in Throttle Gimgal Joints
5	108	Additional Foothold in MGB Lateral Cowlings
6	109	Improved Ventilation Window for Pilots and Co-Pilots Doors
7	110	Rework of Twist Grip Throttle Installation
8	111	Relocation of Fire Extinguisher
9	112	Rework of the Droop Restrainer Stirrup
10	115	Fitment of Rear Crosstube Steps
11	117	Provision of Rings for Fitment of MC-1A Seatbelts
12	118	Squirrel Aircraft, Standardisation of Utility Outlet
13	119	Fitment of MC-1A Seat Belts to Rear Seats of Squirrel AS350B Aircraft
14	122	Removal of Left and Right Hand Push to Talk (PTT) Foot Switched
15	123	Installation of Mic-Tel Extension Leads to Pilot and Co-Pilot Positions
16	126	Installation of Covers Over Flight Control Belcrank Holes in Workdeck
17	127	Installation of Additional Guard for the Hydraulic Isolation Switch
18	129	Replacement of the Adjustable Rod on the Co-Pilots Windscreen Wiper Assembly
19	130	Improvement to Cabin Doors
20	131	Installation of New Blanking Plug to Main Fuel Tank
21	132	Squirrel FM Squelch Tone Enable
22	134	Enlargement of the Fuel Filter Drain Feedthrough Hole
23	135	Introduction of Improved Main Rotor Shaft PN 350A37-1076-07
24	136	Incorporation of a "No Step" Guard Over the Engine Oil Tank Connections
25	137	Repositioning of the Pilots and Co-Pilots Door Jettison Handle
26	138	Re-Routing of IFF Coaxial Cable
27	139	Replacement of Throttle Cams and Solenoids
28	140	Flexible Attachment of Vibration Absorber Fairing
29	141	Provision of Salt Water Activation of Emergency Flotation Equipment
30	146	Squirrel Standby Compass Repositioning
31	147	Protection of the Hoist Cable
32	149	Introduction of Improved Hydraulic Reservoir Fluid Level Indication
33	151	Installation of Inertial Vertical Speed Indicator
34	153	Introduction of Modified Rear Fairing
35	154	Installation of Deflector for Cabin Heater Outlet
36	155	Introduction of a Switch Guard for the Float Firing Switches
37	156	Introduction of Hoist Isolation and Cable Cut Switches
38	157	Disconnection of Squirrel Door Warning
39	158A	Luggage Compartment Door Open Warning System
40	158B	Luggage Compartment Door Open Warning System
41	161	Improved Locking of Main Gearbox and Engine Cowlings
42	162	Introduction of an Access Hole to Reference Point 2

Serial (a)	Mod No (b)	Title (c)
43	164	Introduction of Improved Yaw Control Cover Panel
44	166	Introduction of Drain Valve to Fuel Tank Sump
45	167	Installation of Front Cross Tube Securing Rings
46	168	Introduction of Collective Lever Load Compensation
47	171	Introduction of Bistable Locking Mechanism for Sliding Doors
48	172	Improved HF Aerial Bracket Brackets
49	173	Fitment of Security Chain for Fuel Tank Filler Cap
50	174	Improved Co-Pilot's Cyclic Stick Boom
51	175	Provision for Additional Ballast in Tail Boom
52	177	Squirrel, Twist Grip Throttle, Improved Reliability Components
53	179	Introduction of Improved Cabin Door Seal
54	180	Addition of a Differential Pressure Switch on the Fuel Filter
55	181	Removal of Rear Seat Support Lugs
56	185	Improvement of HSI Digital Circuitry
57	186	Introduction of Protective Pads Around Mooring and Blade Fold Attachment Points
58	187	Reversal of the Extend/Retract Function of the Searchlight Control Switch
59	190	Introduction of Improved Throttle Components to Reduce Backlash
60	191	Emergency Flotation Equipment Float Fire Switch - Replacement
61	192	Instrument Panel Modification
62	193	Introduction of New Ball Joint Pin on Sliding Door
63	195	Rear Seat Cushion Restraint
64	196	Additional Support for Fuel Drain Line
65	198	Removal of Fuel Tank Purge Leaver and Control Cable
66	203	Introduction of Improved Transmission Deck Hand Holds
67	207	Introduction of Rear Seat Pan Restraining Straps
68	210	Attachment of ADF-60 Antenna Backing Plate to Aircraft
69	219	Correction of the Course Deviation Error in the TACAN System
70	220	Introduction of Tail Boom Capable of Reinforced Horizontal Stabiliser
71	222	Improvements to Sliding Doors And Supports
72	225	Removal of IF Screen Support Strips
73	226A	Correct Positioning of Co-Pilots Cyclic Stick
74	228	Replacement of Honeywell Assembly Army Aircraft Only
75	230	Elimination of Heat Shrinkable Sheath from Yellow Pitch Change Rod
76	241	Bleed Valve Amend Aircraft Wiring
77	242	Fitment of Additional VHF
78	244	Transmission Deck Reinforcement
79	245	Enlargement of Collective Control Passage
80	247A	BA Upgrade
81	248A	Wider Chord Tail Rotor
82	250	Introduction of Compass Slaving Assembly KA51B
83	NSM Squirrel 005	Squirrel Controls Instrumentation
84	NSM Squirrel 006	Novatel Gizmo GPS Installation

Table 1-A-1: Modification State of Test Aircraft A22-009

SCOPE OF THE TEST

SORTIE DETAILS

1. The 'Hydraulics Out' flight test program was split into two phases: Phase 1 involved flight testing four ADFHS aircraft to select the test aircraft; Phase 2 was the formal Flight Test Program (FTP) at RAAF Base Edinburgh over the period 13 May 97 to 17 Jun 97. The FTP was flown in good weather and winds below 15 kts. The assessing pilot sat in the right seat, with the FTE in the left seat. A detailed list of FTP sorties is provided in Table F-1.

TEST CONFIGURATION

2. The aircraft was flown in the clean configuration with rear doors closed and locked. No role equipment (hoist) was fitted to the aircraft. During the Phase 2 FTP an ARDU developed instrumentation suite weighing 23 kg was strapped to the rear cabin floor.

WEIGHT AND BALANCE

3. The FTP was conducted at 2100 kg and 1950 kg at varying CGs. The CG was varied using ballast in the rear cabin and side and rear baggage compartments. CG was calculated using a spreadsheet application by the procedure described in Section 5 of the AS350BA Flight Manual (reference F). A load summary for Phase 2 testing is included in Table F-1 and is displayed, for each test sortie, in Figure F-1.

TEST LIMITATIONS

4. The Flight Manual limitations were observed during all testing. The assessed envelope encompassed airspeeds from the hover to 70 KIAS in the 2 100 kg and 1 950 kg weight and CG envelope. Additionally, a low speed envelope of winds to 30 Knots from Green and Red (30 degrees) was assessed.

FLT SERIAL	DATE	DURATION	DESCRIPTION	CG Regime[1]	AIRCRAFT [kg]	CARGO [kg]			FUEL [%]		AUW [kg]		R-AUW[2] [kg]	CG [m]		WEATHER[3]			
						(a) CABIN	(b) SIDE	(a) AFT	T/O	LAND	TO	LAND		TO	LAND	Wind	OAT	QNH	VISIBILITY
(a)	(b)	(c)	(d)	(e)	(f)				(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)
PH1-1	15-Apr-97	1.3	Hyd OFF assessment of fleet acft (A22-010)	M-M	1367	0	0	0	60	35	1744	1639	1870	3.31	3.30	160/8	19	1021	<8
PH1-2	16-Apr-97	1.2	Hyd OFF assessment of fleet acft (A22-009)	M-M	1382.85	0	0	0	52	30	1726	1634	1789	3.31	3.30	L&V	10	1024	>10
PH1-3	16-Apr-97	0.9	Hyd OFF assessment of fleet acft (A22-019)	M-M	1367	0	0	0	60	39	1744	1656	1858	3.31	3.31	L&V	18	1024	>10
PH1-4	16-Apr-97	1.0	Hyd OFF assessment of fleet acft (A22-023)	M-M	1381	0	0	0	60	32	1758	1641	1909	3.32	3.30	300/8	22	1019	>10
PH2-01	13-May-97	0.5	Shakedown Sortie	L-M	1382.85	0	0	0	40	30	1699	1657	1667	3.29	3.29	110/10-15	13	1028	CAVOK
PH2-02	13-May-97	1	Trim Points/Hyd Accell	L-M	1382.85	0	0	0	40	20	1699	1615	1689	3.29	3.28	090/6	16	1025	>10
PH2-03	14-May-97	1	Hyd ON/ISOL/TEST Landings	H-M	1382.85	0	0	0	80	54	1866	1758	1819	3.31	3.30	080/5	10	1024	CAVOK
PH2-04	14-May-97	0.9	Hyd ON/ISOL/TEST Landings	L-M	1382.85	0	0	0	40	12	1699	1582	1672	3.29	3.28	040/5-10	13	1025	CAVOK
PH2-05	14-May-97	0.7	Trim Points/Hyd Accell	H-M	1382.85	0	0	0	75	60	1845	1783	1847	3.31	3.30	L&V	17	1022	CAVOK
PH2-06	15-May-97	1	Hyd ON Landings & LSTFCP[4]	H-A	1382.85	0	200	80	70	50	2104	2021	2060	3.35	3.34	100/5-10	11	1023	CAVOK
PH2-07	15-May-97	0.6	Hyd ON Landings & LSTFCP	H-F	1382.85	307	0	0	50	37	2048	1994	2014	3.15	3.14	VRB/5-10	10	1015	> 10 KM
PH2-08	15-May-97	0.7	Trim Points/Hyd Accell	H-A	1382.85	0	200	80	70	54	2104	2038	2108	3.35	3.34	040/5-15	17	1021	> 10 KM
PH2-09	23-May-97	0.8	Hyd ON Landings & LSTFCP (data validation)	H-A	1382.85	0	200	80	70	48	2104	2012	2110	3.35	3.34	L&V	17	1020	> 10 KM
PH2-10	26-May-97	0.7	Trim Points/Hyd Accell	H-F	1382.85	326	0	0	45	28	2046	1975	2066	3.13	3.12	150/5-10	17	1013	> 10 KM
PH2-11	2-Jun-97	0.5	Hyd ISOL/TEST Landings & LSTFCP	H-A	1382.85	0	200	80	70	50	2104	2021	2086	3.35	3.34	O10/10-15	14	1021	CAVOK
PH2-12	3-Jun-97	0.8	Hyd ISOL/TEST Landings & LSTFCP	M-M	1382.85	100	0	0	80	55	1966	1862	1984	3.26	3.25	350/10-15	18	1017	CAVOK
PH2-13	7-Jun-97	0.8	Hyd ISOL/TEST Landings	M-M	1382.85	100	0	0	80	59	1966	1878	1896	3.26	3.25	030/5-10	8	1028	>10
PH2-14	7-Jun-97	0.9	Hyd ISOL/TEST Landings & LSTFCP	M-A	1382.85	0	100	80	70	50	2004	1921	1965	3.35	3.35	340/5-10	13	1029	>10
PH2-15	7-Jun-97	0.7	Hyd ISOL/TEST Landings & LSTFCP	M-MF	1382.85	160	60	0	50	30	1961	1877	1942	3.21	3.20	250/10-15	16	1029	>10
PH2-16	8-Jun-98	0.9	Hyd ISOL/TEST Landings & LSTFCP	M-F	1382.85	220	0	0	50	33	1961	1890	1906	3.18	3.17	030/5	12	1034	>10
PH2-17	8-Jun-97	0.7	Hyd ISOL/TEST Landings & LSTFCP	M-MF	1382.85	100	0	0	80	60	1966	1883	1933	3.26	3.25	360/5	15	1033	>10
PH2-18	16-Jun-97	0.6	Hyd ISOL/TEST Landings & LSTFCP (COOMA)	M-M	1382.85	0	0	0	78	62	1658	1791	1952	3.31	3.30	NO ATIS AVAILABLE (OAT 3)			
PH2-19	17-Jun-97	1.1	Hyd ISOL/TEST Landings & LSTFCP (CANB)	M-M	1382.85	0	0	0	81	53	1870	1753	1926	3.31	3.30	150/8	10	1030	>10

Notes:

1 General Description of CG regime - Format: X-Y: X is acft AUW (L-Light, M-Medium, H-Heavy) Y is approx. CG location (F-Fwd, MF-Mid Fwd, M-Mid, A-Aft)
2 RAUW: Refered All Up Weight
3 Weather details obtained from ATIS at beginning of each sortie.
4 LSTFCP - Low Speed Trim Flight Control Positions
5 Transit of aircraft accounted for 10.3 hrs (ASCB-YPED: 4.8 hrs, YPED-YCOM-ASCB: 5.5)
6 PH represents the Phase of the investigation: Phase 1 - test acft selection, Phase 2 - flight test investigation
7 Weight of pilots 157 kg, weight of DAS (Ph2 only) 23 kg

Table F-1: Flight Test Program Summary

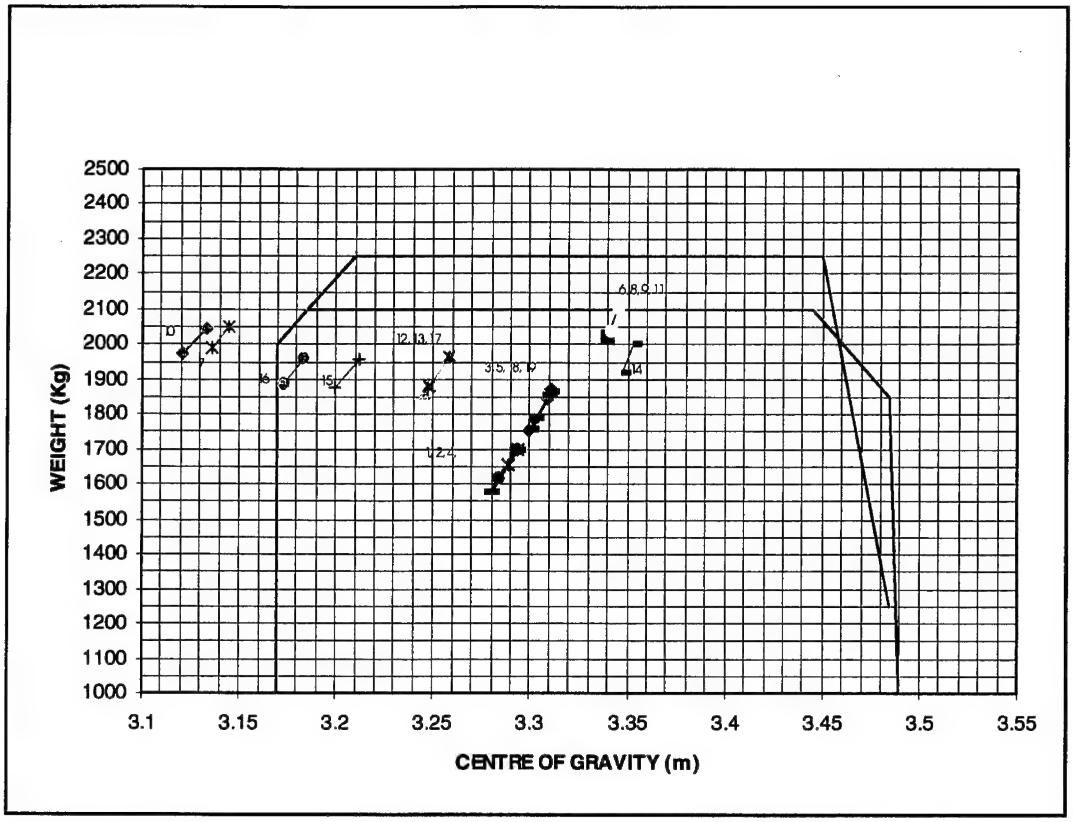


Figure F-1: AS350BA Loading Chart with Phase 2 Test Points Annotated

TESTS MADE AND TEST TECHNIQUES

1. **Tests Made.** The tests made are summarised in Table G-1.

FLIGHT SERIAL	DESCRIPTION
PH1-01	Hyd OFF assessment of fleet acft (A22-010)
PH1-02	Hyd OFF assessment of fleet acft (A22-009)
PH1-03	Hyd OFF assessment of fleet acft (A22-019)
PH1-04	Hyd OFF assessment of fleet acft (A22-023)
PH2-01	Shakedown Sortie
PH2-02	Trim Points/Hyd Accell
PH2-03	Hyd ON/ISOL/TEST Landings
PH2-04	Hyd ON/ISOL/TEST Landings
PH2-05	Trim Points/Hyd Accell
PH2-06	Hyd ON Landings & LSTFCP[3]
PH2-07	Hyd ON Landings & LSTFCP[3]
PH2-08	Trim Points/Hyd Accell
PH2-09	Hyd ON Landings & LSTFCP[3] (data validation Flight)
PH2-10	Trim Points/Hyd Accell
PH2-11	Hyd ISOL/TEST Landings & LSTFCP[3]
PH2-12	Hyd ISOL/TEST Landings & LSTFCP[3]
PH2-13	Hyd ISOL/TEST Landings
PH2-14	Hyd ISOL/TEST Landings & LSTFCP[3]
PH2-15	Hyd ISOL/TEST Landings & LSTFCP[3]
PH2-16	Hyd ISOL/TEST Landings & LSTFCP[3]
PH2-17	Hyd ISOL/TEST Landings & LSTFCP[3]
PH2-18	Hyd ISOL/TEST Landings & LSTFCP[3] (COOMA RW[4] 1950kg)
PH2-19	Hyd ISOL/TEST Landings & LSTFCP[3] (CANBERRA. RW[4] 1950kg)

Table G-1: Tests Made

2. **Test Techniques.** The general test techniques employed were according to References D and E. Some specific techniques used are outlined in the following paragraphs.

3. The flight tests consisted of the following manoeuvres over the weight and CG variation indicated in Annex F.

a. A series of stabilised trim points to determine control forces and workload via a Handling Quality Rating (HQR) awarded IAW Table G-2 conducted at 1000' and 5000' pressure altitude.

b. A series of accelerations and decelerations between 30 and 70 KIAS noting control forces and positions conducted at 1000' and 5000' pressure altitude.

c. A series of approaches to a hover landing (zero wind and other conditions up to 30 knots within 30 degrees of touchdown heading) and running landings to 30 Knots in 5 Knot increments with the HQR Performance parameters in Table G-2 applied. A debrief was conducted after each touch down and a HQR awarded. Approaches were made with the hydraulics selected ON, ISOL and TEST.

4. The effect of selecting trim ON and the use of cyclic and collective friction to reduce forces and workload required was investigated during a heavy weight sortie.

5. Low speed trim flight control position assessment with hydraulics selected ON, TEST and ISOL was conducted corresponding to the SHOL limits for the degraded mode with hydraulics OFF IAW Reference I. This involved a clearance from 0 to 30 Knots for green 30 and red 30 relative winds at weights up to 2100 kg with forward and aft CGs using GPS and wind information for the tower or other ground base anemometer to set wind velocity through the rotor disc.

6. Low speed stability and control tests at high weights were split into two sorties to enable confirmation through revision of test data gathered with the hydraulics selected ON, that control margins were adequate before proceeding to hydraulics out test points (given the reduction in control authority in the hydraulics ISOL or TEST modes).

7. **Rating Scales.** The Cooper-Harper Handling Qualities Rating Scale, presented in figure G-1, was used to assess the handling qualities of the aircraft. The tolerances applied to the flying tasks assessed during the test flying are listed in table G-2 below.

Serial (a)	Task (b)	Performance Parameter (c)	Desired Performance (d)	Adequate Performance (e)
1	Hydraulics off Precision Hover	Heading control	± 5 deg no yaw rate at touchdown	± 10 deg yaw rate < 2 deg/sec
	Landing	Plan Position	± 2 ft no drift lateral or longitudinal	± 4 ft < 0.25 ft /sec drift lateral or longitudinal
		Altitude	±1 ft <50 ft/min ROD (smooth touchdown)	±3 ft < 100 ft/min ROD (firm touchdown)
2	Hydraulics off Running Landing	Heading control	± 2.5 deg	± 5 deg
		Landing Point	± 20 ft	± 50 ft
		Altitude	± 3 ft <50 ft/min ROD (smooth touchdown)	± 5 ft < 100 ft/min ROD (firm touchdown)
3	Hydraulics off High Hover (for low speed trim flight control positions)	Heading control	± 10 deg	± 20 deg
		Plan Position	± 5 ft	± 10 ft
		Altitude	± 5 ft	± 10 ft
4	Hydraulics off Level Flight	Airspeed	± 5 KIAS	± 10 KIAS
		Balanced Flight (yaw string central)	± 2.5 deg	± 5 deg
		Altitude	± 50 ft	± 100 ft

Table G-2: Handling Quality Rating Performance Parameters

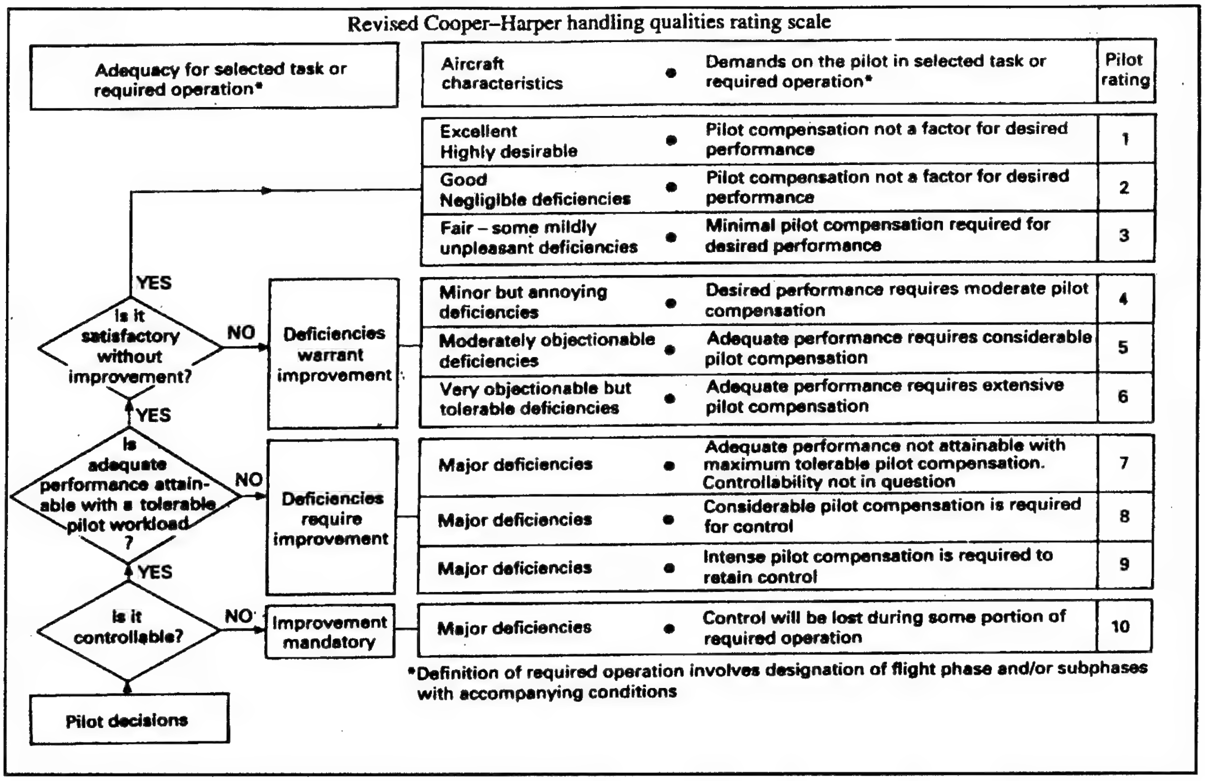


Figure G-1: Cooper-Harper Handling Qualities Rating Scale

GROUND TEST DATA

Where displayed, the displacement in mm refers to the control (collective, pedal or cyclic) or respective servocontrol travel.

COMMON DATA

Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: Varying Position (installed forwards)
Tailnumber: A22-009	Location: EDN - Inside Hangar	Cyclic Stick: CR Position
Date of Test: 17 Jun 97	Engines and Rotors Stopped	Collective: Envelope
Aircraft Hours: 4519.5	External Hydraulic & Electric Power Connected	Seat Fully Forward

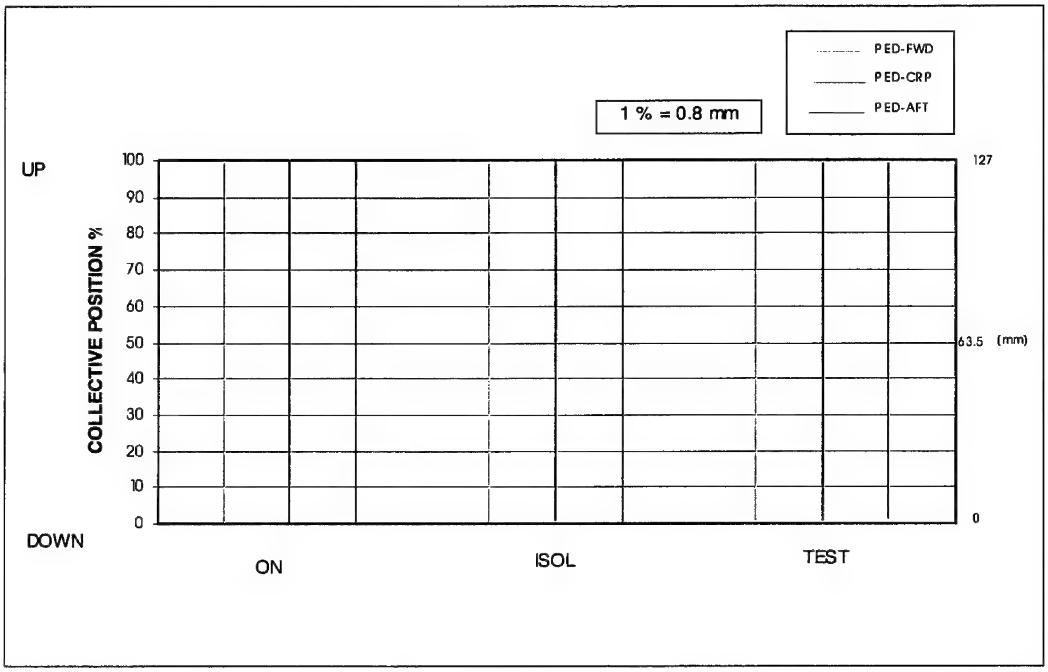


Figure H-1: Collective Envelope with Varying Pedal Position

COMMON DATA

Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: Varying Position (installed forwards)
Tailnumber: A22-009	Location: EDN - Inside Hangar	Cyclic Stick: CR Position
Date of Test: 17 Jun 97	Engines and Rotors Stopped	Collective: Envelope
Aircraft Hours: 4519.5	External Hydraulic & Electric Power Connected	Seat Fully Forward

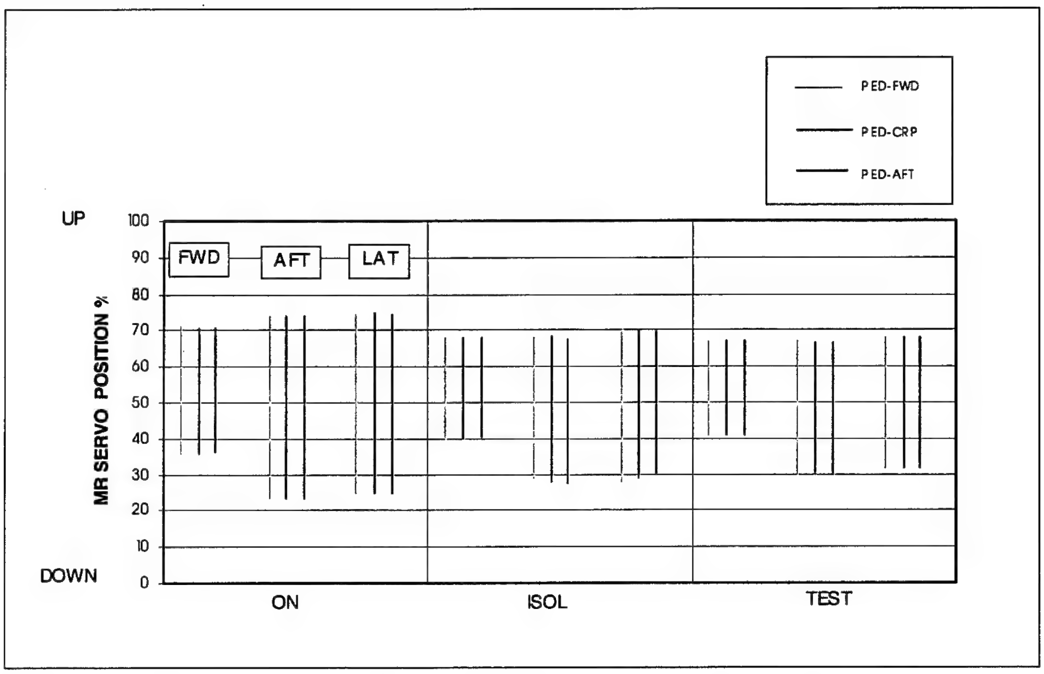


Figure H-2: Mainrotor Servo (Collective) Envelope with Varying Pedal Position

Note:

1 On average each mainrotor servo moved 41 mm for full collective displacement hydraulics ON. The remaining movement of the servo was to effect cyclic control.

COMMON DATA

Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: CR Position (installed forwards)
Tailnumber: A22-009	Location: EDN - Inside Hangar	Cyclic Stick: Envelope
Date of Test: 13 May 97	Engines and Rotors Stopped	Collective: Down, Mid and Up
Aircraft Hours: 4494.7	External Hydraulic & Electric Power Connected	Seat Fully Forward

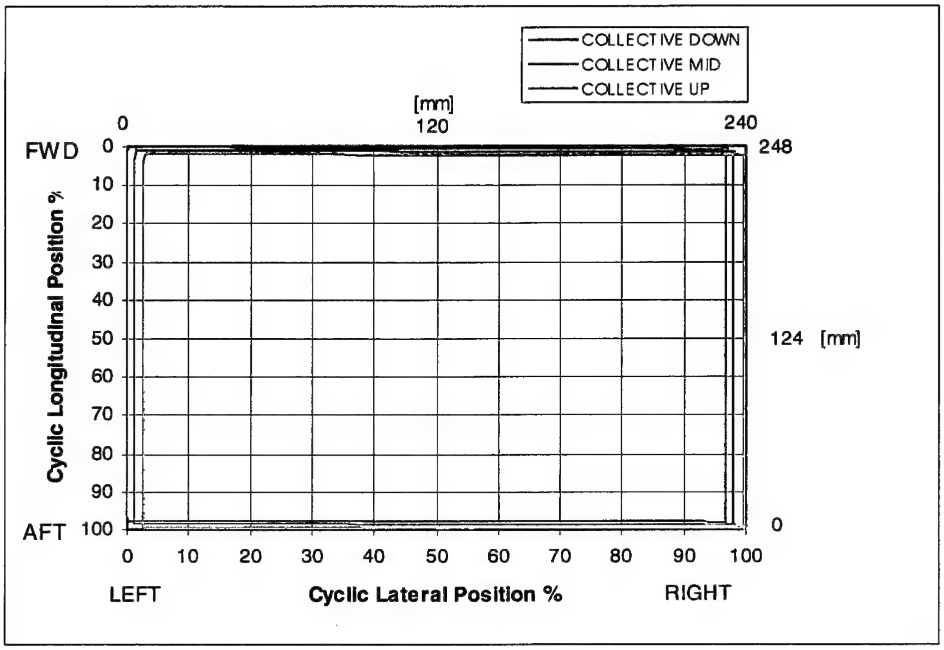


Figure H-3: Cyclic Envelope with Varying Collective Position

COMMON DATA		
Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: Envelope
Tailnumber: A22-009	Location: EDN - Inside Hangar	Cyclic Stick: CR Position
Date of Test: 17Jun 97	Engines and Rotors Stopped	Collective: Down, Mid and Up
Aircraft Hours: 4519.5	External Hydraulic & Electric Power Connected	Seat Fully Forward

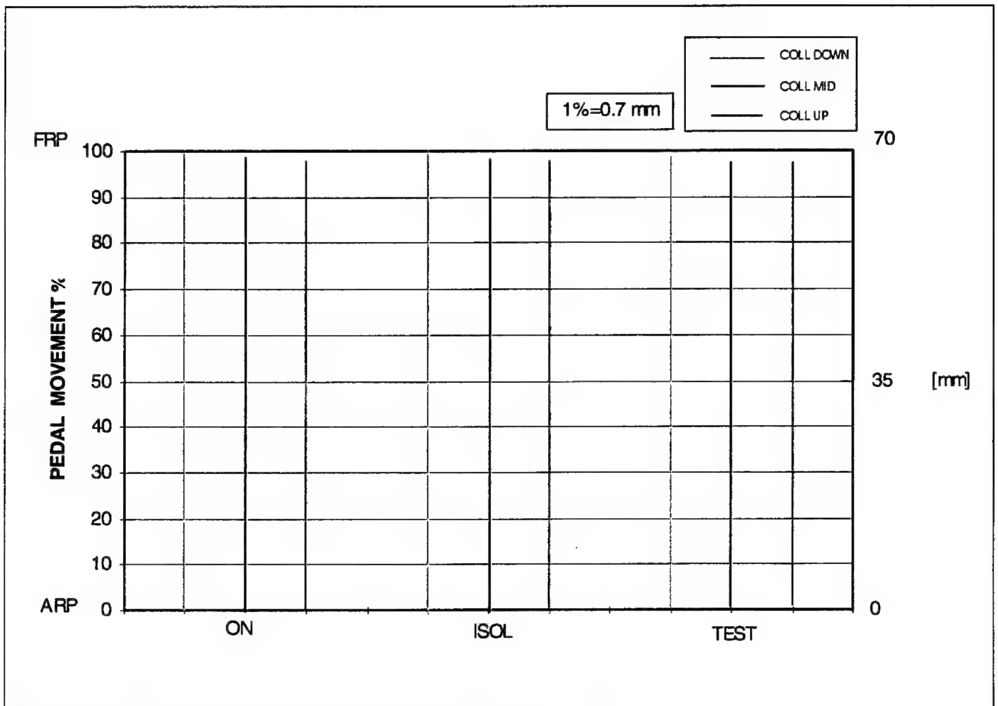


Figure H-4: Pedal Movement vs Collective Position

COMMON DATA		
Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: Envelope
Tailnumber: A22-009	Location: EDN - Inside Hangar	Cyclic Stick: CR Position
Date of Test: 17Jun 97	Engines and Rotors Stopped	Collective: Down, Mid and Up
Aircraft Hours: 4519.5	External Hydraulic & Electric Power Connected	Seat Fully Forward

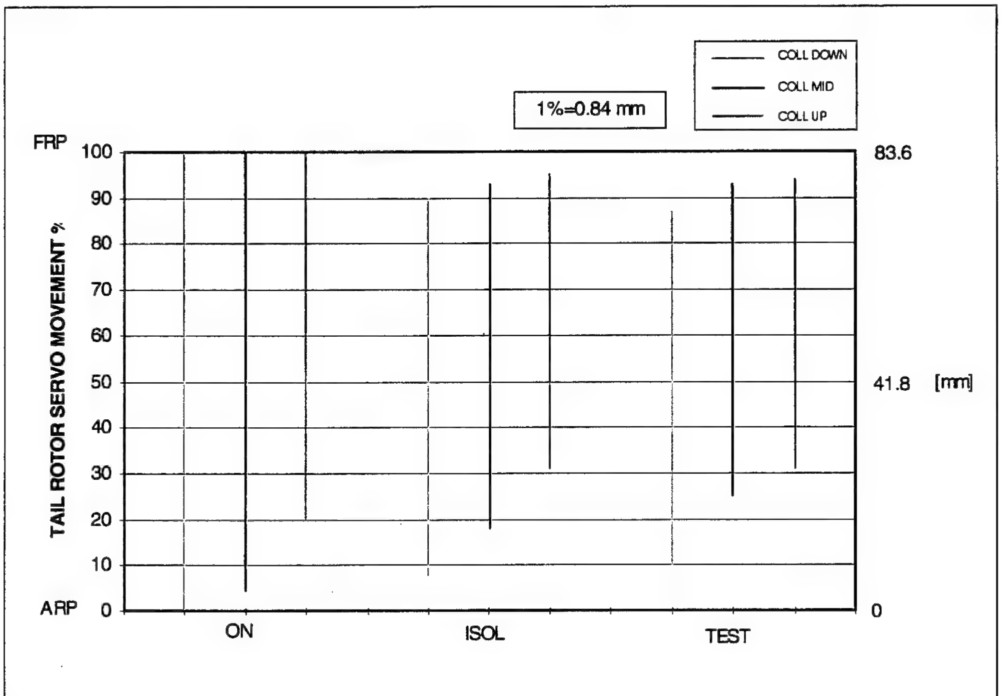


Figure H-5: Tail Rotor Servo Movement vs Collective Position

COMMON DATA		
Aircraft: AS350BA	Front Right Pilot's Station	Yaw Pedals: CR Position
Tailnumber: A22-009	Location: EDN - Inside Hangar	Cyclic Stick: CR Position
Date of Test: 6 May 97	Engines and Rotors Stopped	Collective: Envelope
Aircraft Hours: 4519.5	External Hydraulic & Electric Power Connected	Seat Fully Forward

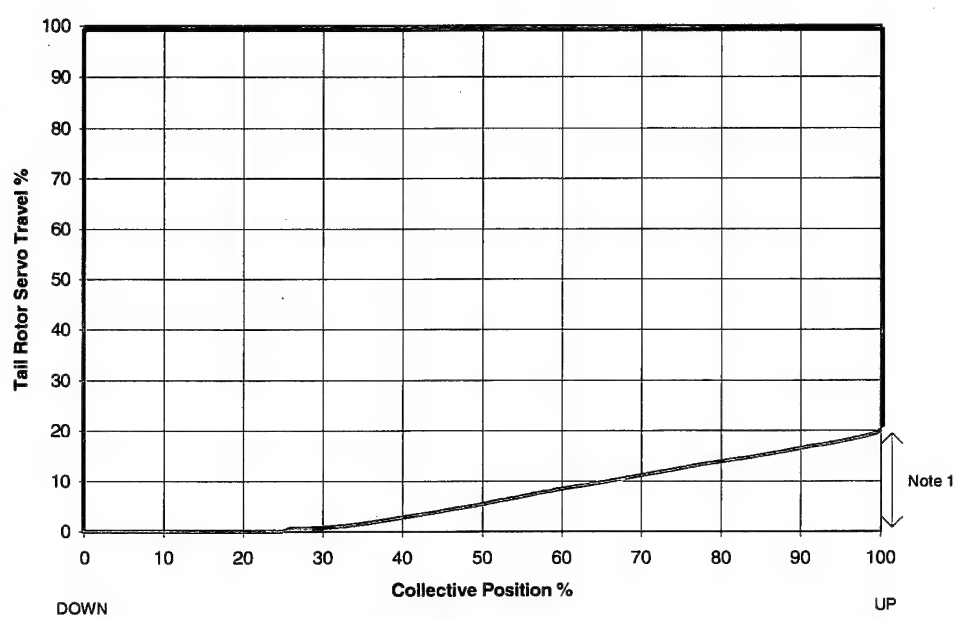


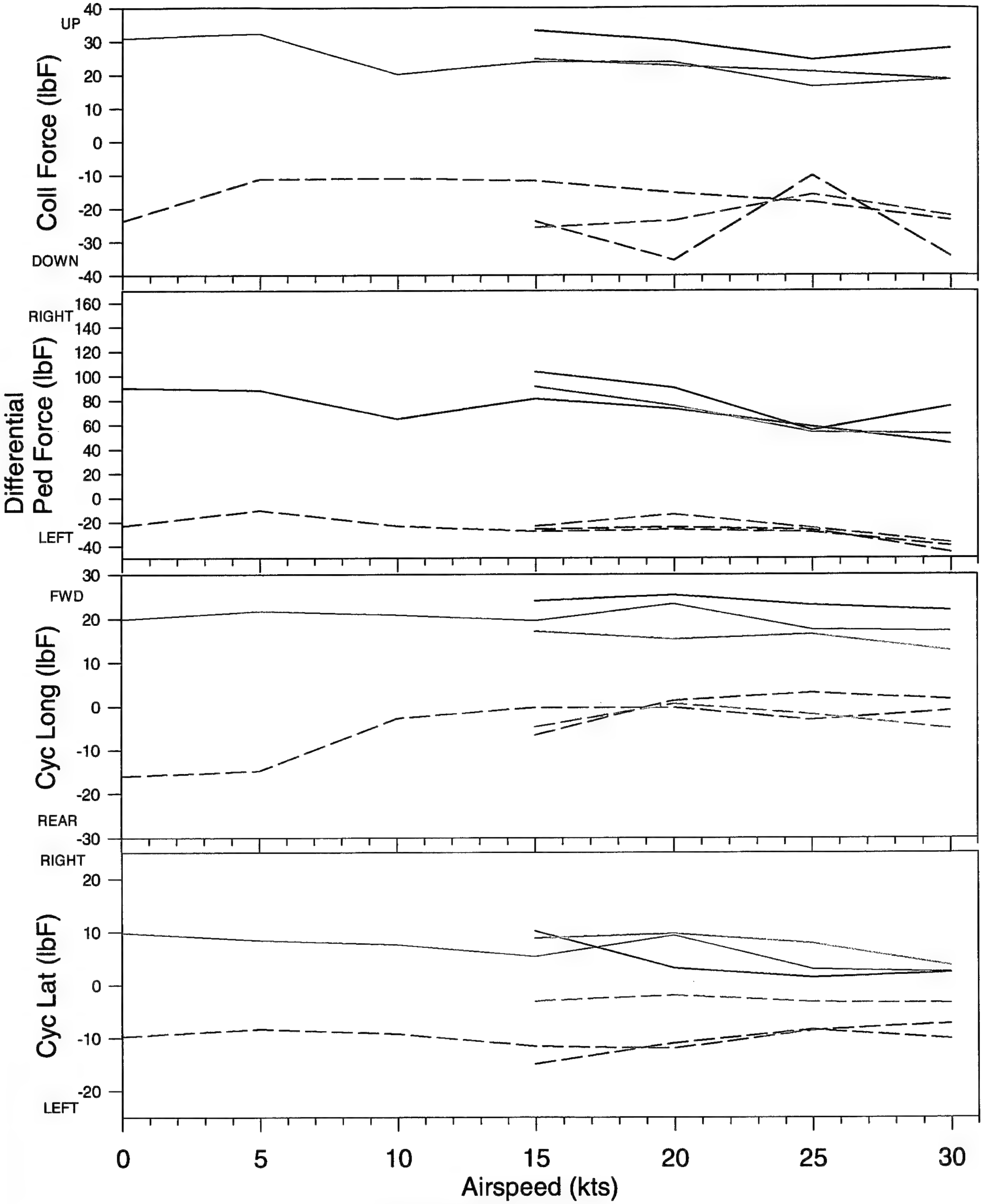
Figure H-6: Tail Rotor Servo Envelope vs Collective Position

Note:

1 Red arrow indicates the input from the Mixing Unit with collective fully UP

FLIGHT TEST DATA

Control Forces for Landing



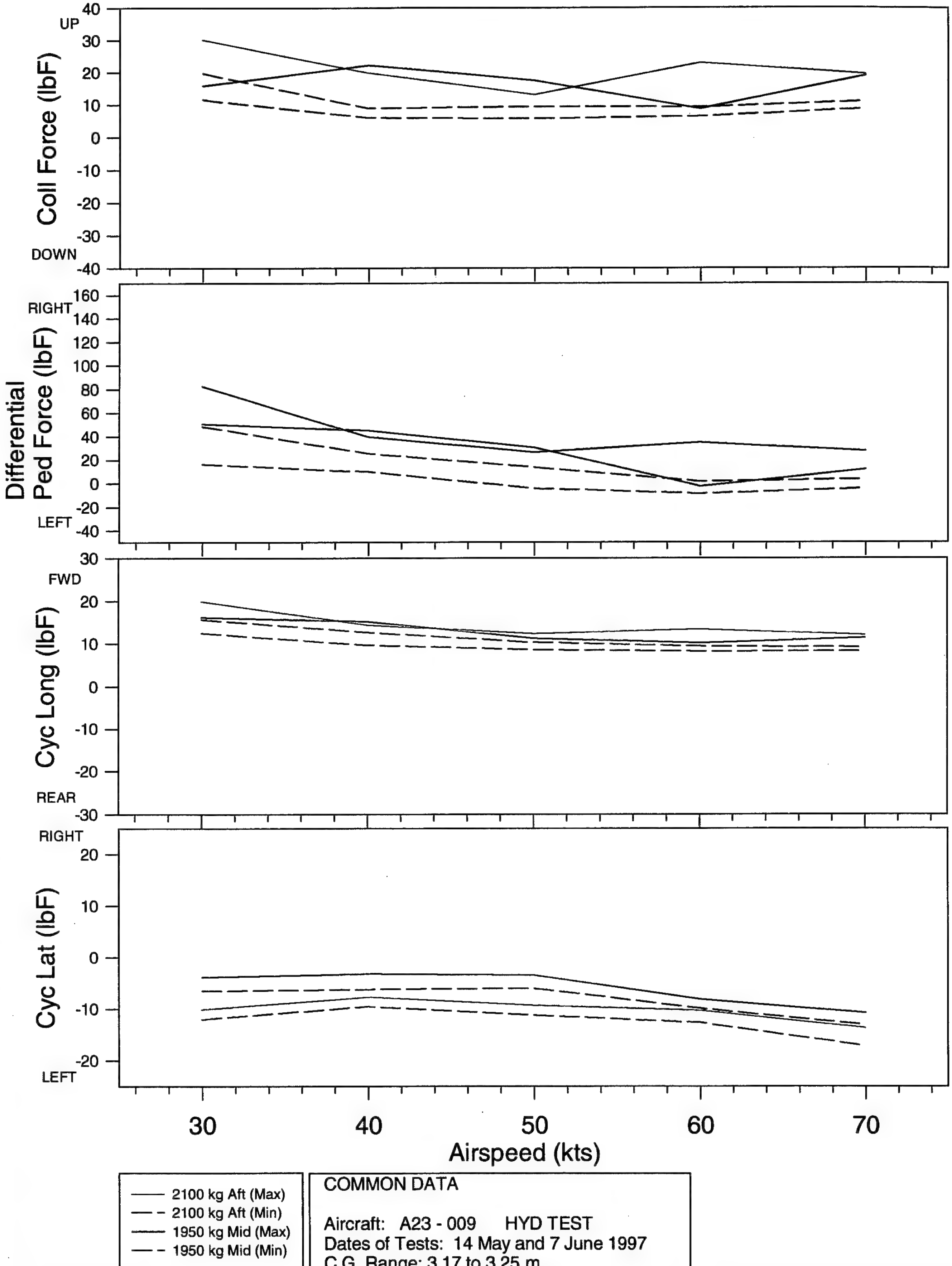
1700 kg Mid C.G. (Max)
1700 kg Mid C.G. (Min)
1950 kg Fwd C.G. (Max)
1950 kg Aft C.G. (Min)
1950 kg Fwd C.G. (Max)
1950 kg Aft C.G. (Min)

COMMON DATA

Aircraft: A23 - 009 HYD TEST
Dates of Tests: 14 May and 7 June 1997
C.G. Range: 3.17 to 3.25 m
All plots are for referred AUW

Figure I - 1

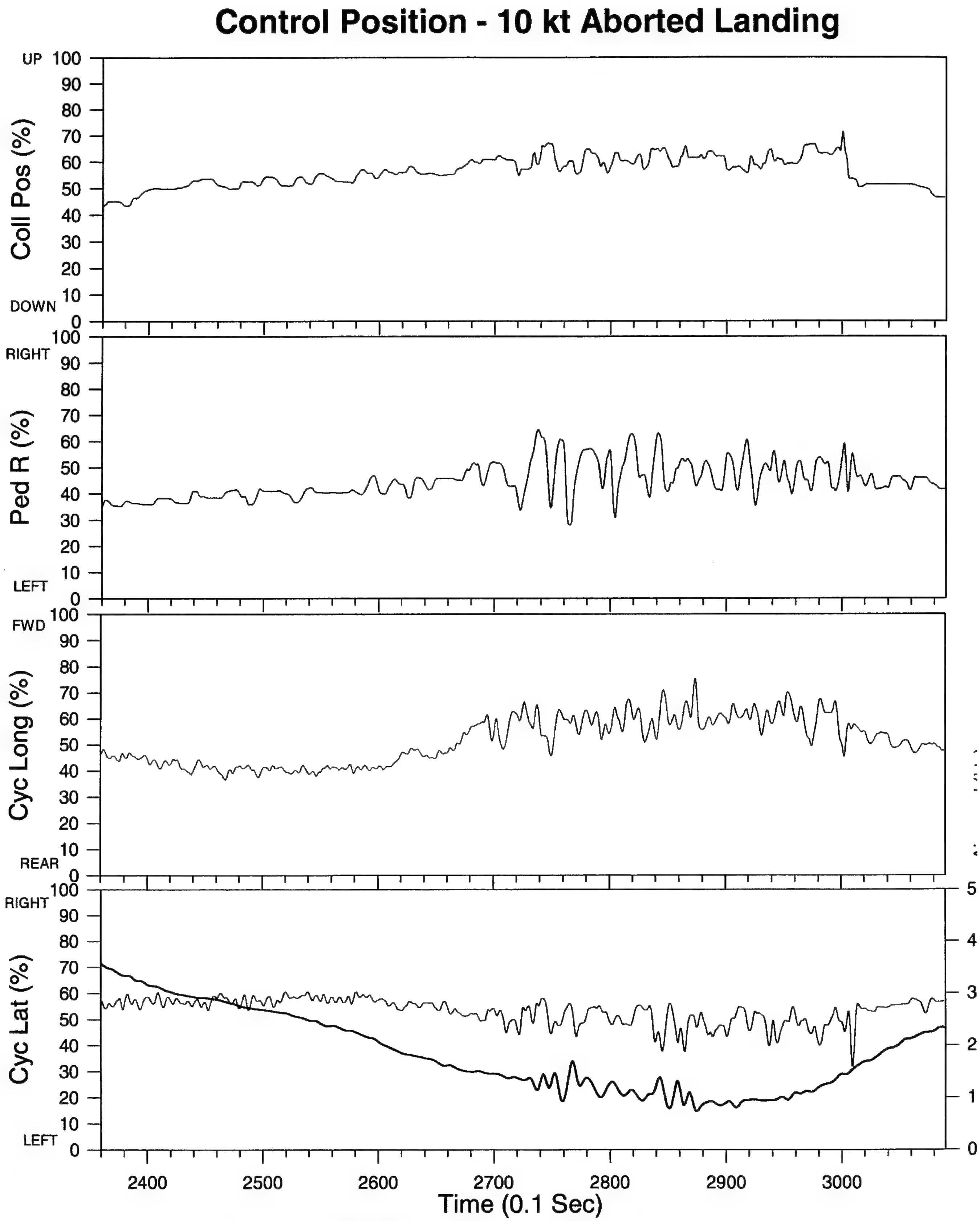
Control Forces in Forward Flight



COMMON DATA

Aircraft: A23 - 009 HYD TEST
Dates of Tests: 14 May and 7 June 1997
C.G. Range: 3.17 to 3.25 m
All plots at 5000 ft PA and ISA

Figure I - 2



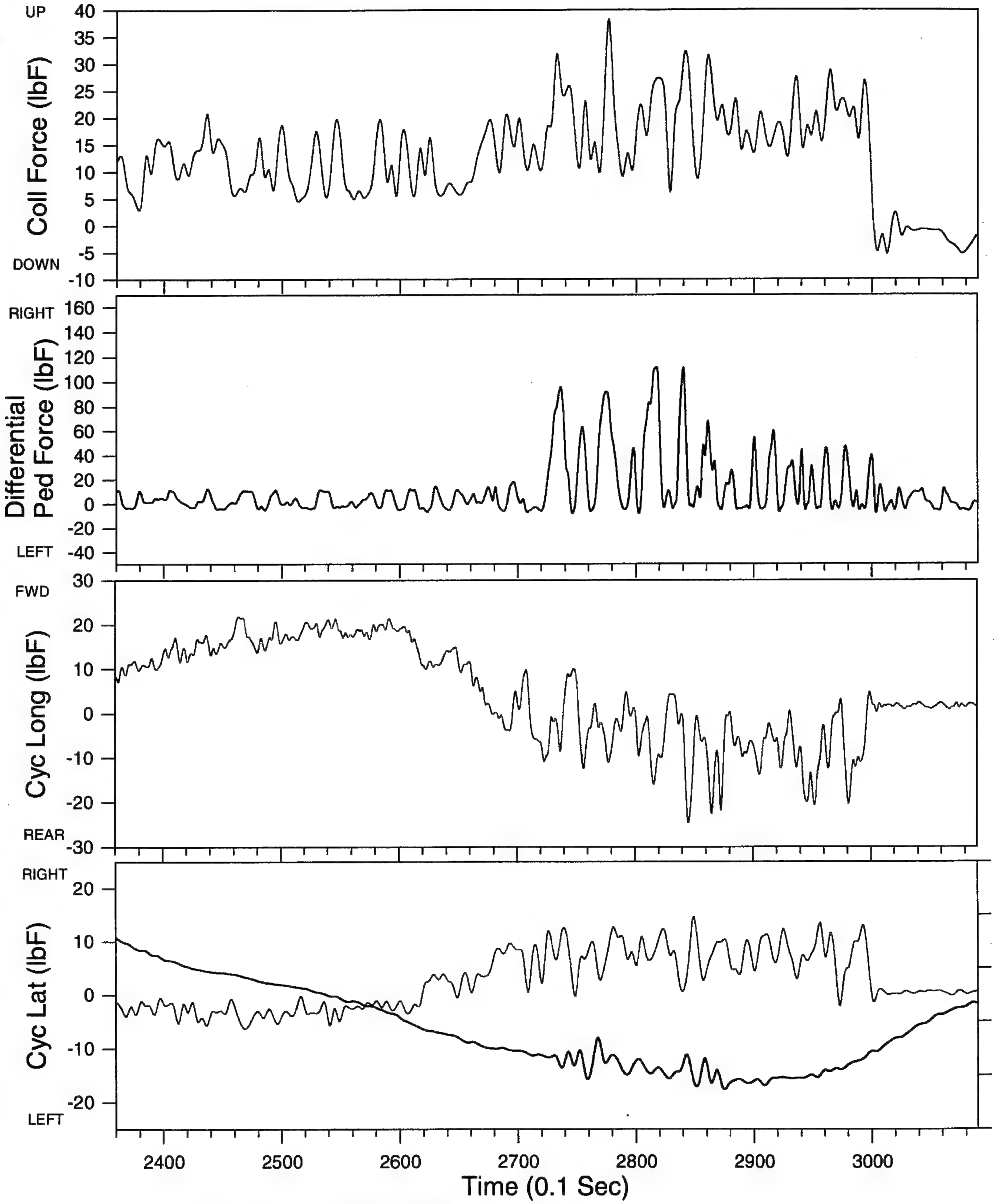
Control Position
Airspeed (kts)

COMMON DATA

Aircraft: A23 - 009 HYD ISOL
Dates of Tests: 7 June 1997
C.G. Range: 3.2 m
All plots are for 1950 kgF referred AUW

Figure I - 3

Control Forces - 10 kt Aborted Landing

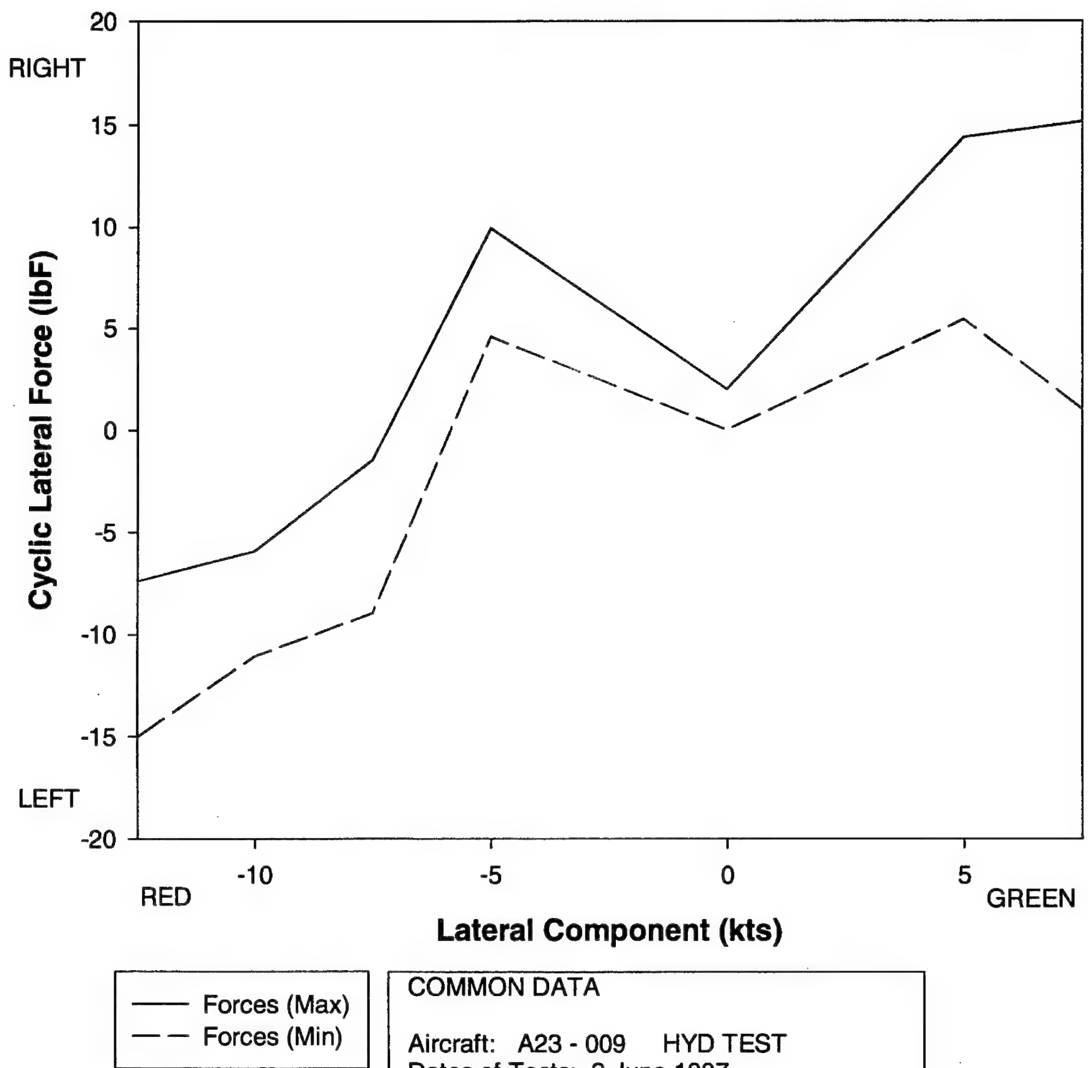


COMMON DATA

Aircraft: A23 - 009 HYD ISOL
Dates of Tests: 7 June 1997
C.G. Range: 3.2 m
All plots are for 1950 kgF referred AUW

Figure I - 4

Lateral Control Forces in Cross Winds

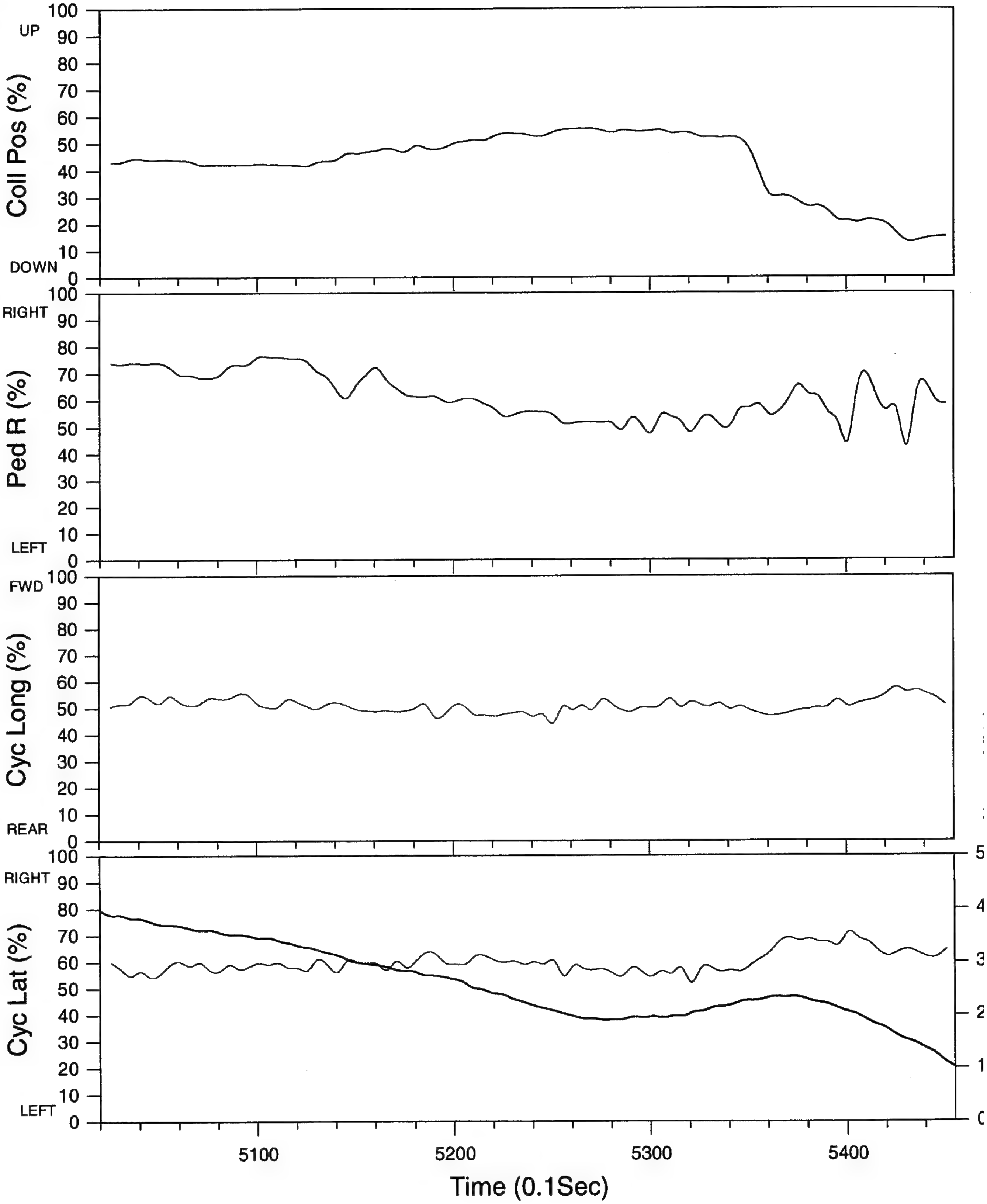


COMMON DATA

Aircraft: A23 - 009 HYD TEST
Dates of Tests: 3 June 1997
C.G. Range: 3.28 m
All plots are for 1950 kgF referred AUW
Aircraft heading 30° to relative airflow

Figure I - 5

Control Position for 20 kt Landing



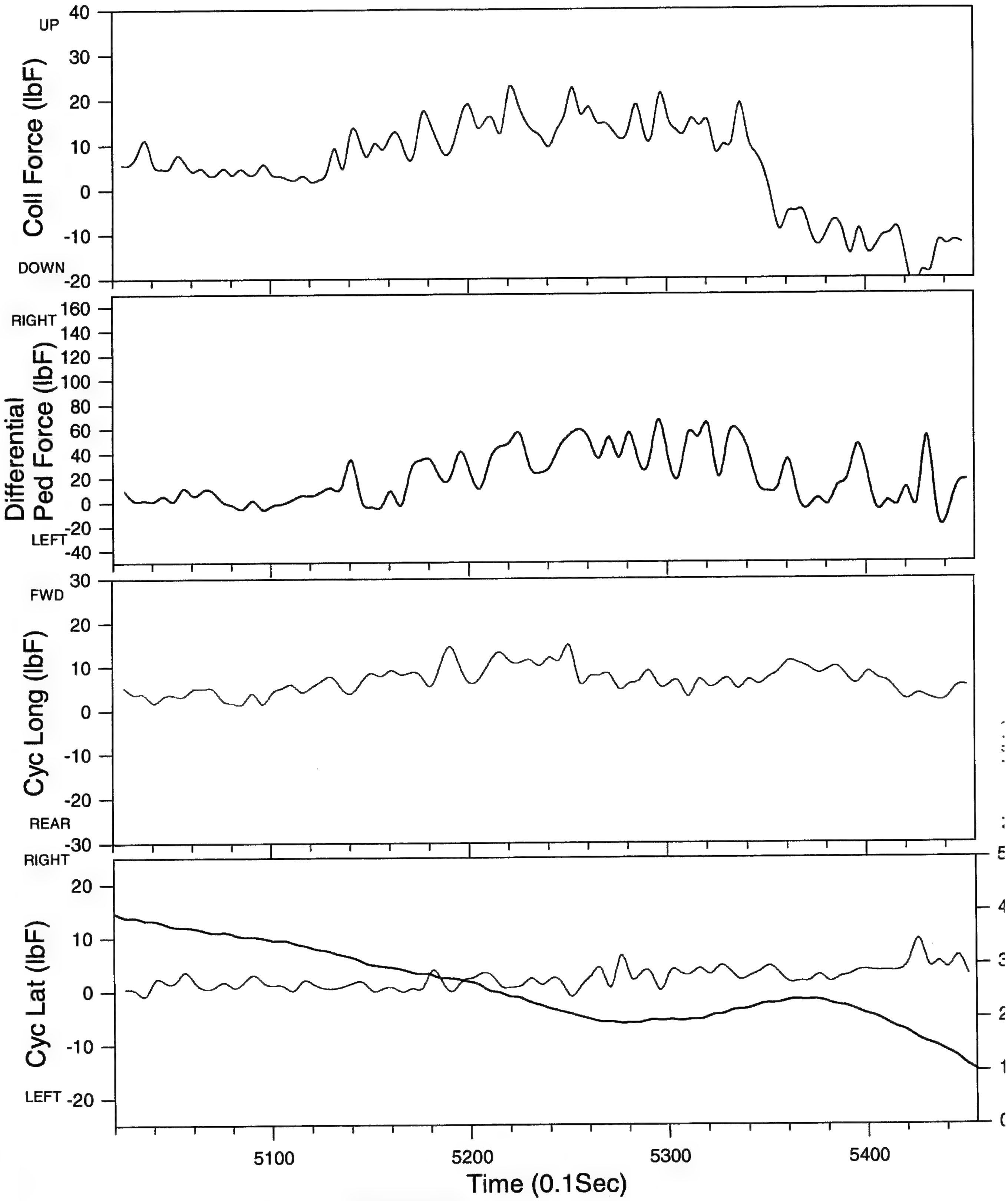
—— Control Position
—— Airspeed (kts)

COMMON DATA

Aircraft: A23 - 009 HYD TEST
Dates of Tests: 7 June 1997
C.G. Range: 3.21 m
All plots are for 1950 kgF referred AUW

Figure I - 6

Control Forces for 20 kt Landing



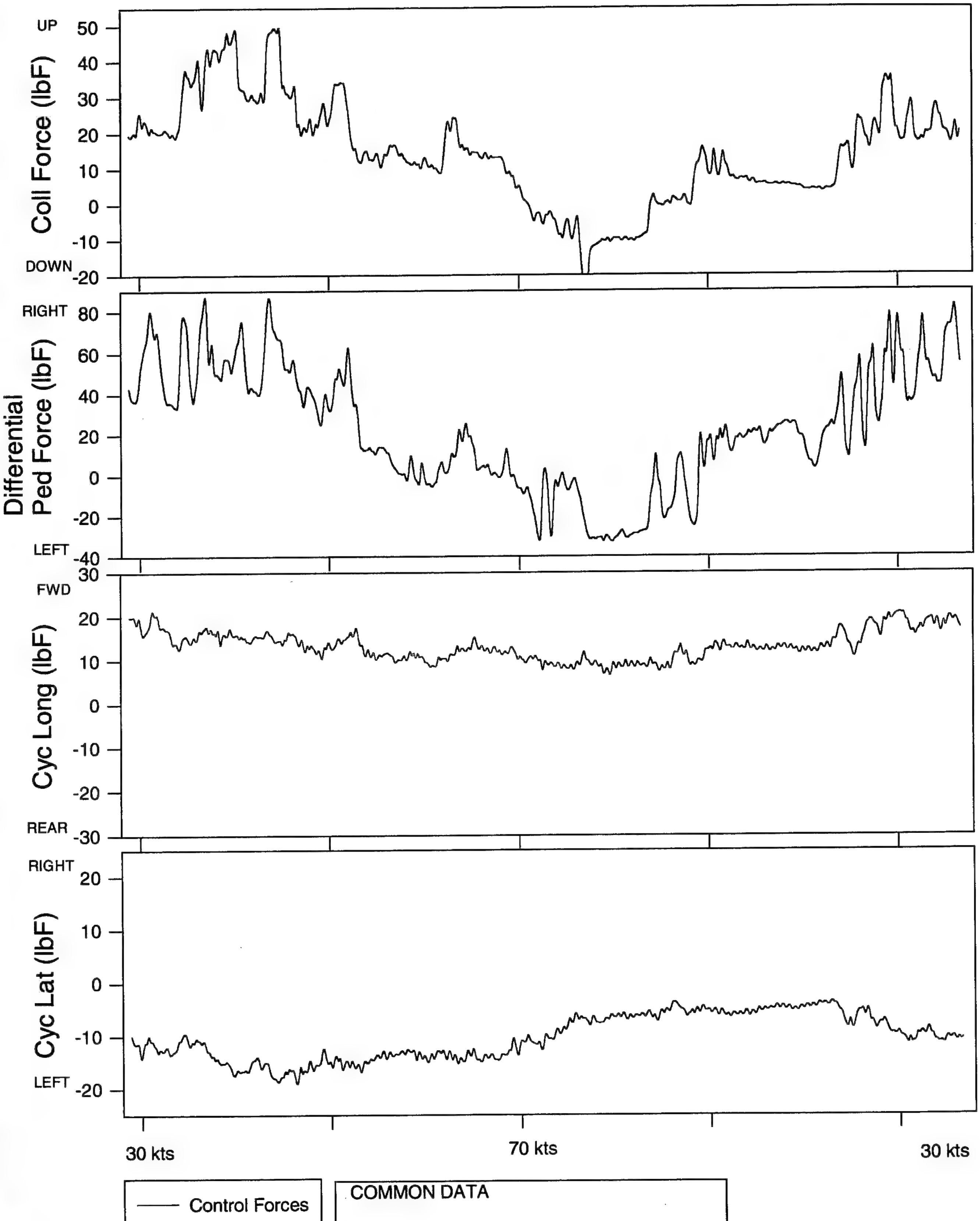
Control Forces
Airspeed (kts)

COMMON DATA

Aircraft: A23 - 009 HYD TEST
Dates of Tests: 7 June 1997
C.G. Range: 3.21 m
All plots are for 1950 kgF referred AUW

Figure I - 7

Control Forces for Acceleration - Deceleration



COMMON DATA

Aircraft: A23 - 009 HYD TEST
Dates of Tests: 15 May 1997
Configuration: 2100 kgF AUW, CG 3.25 m
All plots at 5000 ft PA and ISA

Figure I - 8

ANNEX J TO
FORMAL REPORT
TASK 0301

FLIGHT MANUAL AMENDMENTS

Flight Characteristics

1. The following details on flight characteristics in Hydraulics OUT flight should be used in lieu of that promulgated in Section 6 of Reference A:

FLIGHT WITH HYDRAULICS OUT

Hydraulics OUT flight is characterised by increased control forces and reduced control authority when compared to hydraulics ON flight. The reduction in available control authority is due to freeplay in the hydraulic servo actuators. The high control forces are due to the aerodynamic feedback forces and centrifugal pitching moments from the main and tail rotor in flight. The reduced control authority coupled with the high control forces consequential to the BA upgrade, results in a situation whereby prevention of departures from the desired flight path during landing manoeuvres requires intense pilot compensation to maintain control. Furthermore, aircraft control during landing in the hydraulics OUT configuration will not be possible in some areas of the currently cleared flight envelope. Reversion to hydraulics OUT flight should be made via the ISOL switch selection. This will ensure all pressure in main servo accumulators is dumped simultaneously and avoids differential force gradients in cyclic axes. For ISA sea level conditions and 1950 kg, control forces during the landing phase can be up to 150 lbf in pedal, 15 lbf in lateral cyclic, 30 lbf in longitudinal cyclic and up to 40 lbf in collective. Control forces increase with increases in AUW, aft movement of CG position and increase in DA. Reduction in control authority can be up to 17% in collective and cyclic, 16% for left pedal and 8% for right pedal. Control margins will generally improve with aft movement of the CG and reduction in AUM/DA. Flight tests have confirmed that for calm ISA sea level conditions at airspeeds above 15 knots and AUWs of 1950 kgf , safe landings with adequate control margins can be conducted. The recommended approach speed is 45 KIAS. The minimum speed for landing is 15 knots, however, a wind speed through the disc for touchdown of 20 knots is recommended as it provides the most predictable handling qualities for touchdown. Minimum control forces for level flight occur at 40-45 knots and 35- 45 % Torque depending on AUW and DA. Transit at or below 70 KIAS will quickly lead to aircrew fatigue due to high control forces if this is required (ie over water flight).

WARNING

Aircraft handling qualities degrade rapidly at airspeeds below 15 knots through the rotor disc. For gusty conditions the minimum airspeed through the rotor disc should be increased by half the gust factor.

Emergency Procedures

2. The following emergency procedure should be used in lieu of that promulgated in Section 3 of Reference F:

HYDRAULIC SYSTEM FAILURES

Hydraulic Light Illumination and Warning Horn Activation

1.	**External Load**	**- Jettison**
2.	**Airspeed**	**- Attain 40 - 70 KIAS as soon as possible**
3.	**Autopilot**	**- Disengage (if in use)**
4.	**Horn**	**- Deselect**
5.	**Master Warning/Caution Light**	**- Cancel**
6.	**Hydraulic Test Switch**	**- Confirm OFF**
7.	**Hydraulic Isolate Switch**	**- Isolate when airspeed 40-70 KIAS**
8.	**Horn**	**- Reselect**
9.	**Emergency Call**	**- Broadcast**
10.	**Land as soon as Possible**	**- Carry out Hydraulics off approach and landing**
11.	Conduct normal engine shutdown	- Maintain downward pressure on collective to ensure minimum rotor pitch during rotor wind down

WARNING

Hydraulic fluid is highly flammable. If airframe or engine fire results from hydraulic fluid leak (if present) then land immediately via a power on approach.

WARNING

Aircraft handling qualities degrade rapidly at airspeeds below 15 knots through the rotor disc. For gusty conditions the minimum airspeed through the rotor disc should be increased by half the gust factor.

CAUTION

If hydraulic pressure is lost, the autopilot trim actuators do not have the power to move the control runs. The autopilot must be disengaged otherwise damage to the trim actuators will result.

CAUTION

Flight with hydraulics OUT will lead to rapid fatigue of the flying pilot. In degraded usable cue environments (at Night or in IMC) pilot workload will

increase and fatigue effects will worsen. The aircraft is to be flown clear of cloud and landed as soon as possible.

NOTE

In the event of a hydraulics failure in an IGE hover an immediate landing may be conducted depending on aircraft controllability.

Hydraulic off Approach and Landing

Optimum profile for a hydraulics OUT landing is via a long shallow approach into wind at 40-45 KIAS. At approximately a half mile from intended touchdown point, the aircraft should be slowed to a ground speed corresponding to 20 knots of wind through the disc (appears as a fast jog at 3 feet in nil wind conditions) but no lower than 15 knots of wind through the disc. This speed should be increased in gusty conditions by half the gust factor. The aircraft should be cushioned to the ground with collective and kept straight with pedal. Forward force on the cyclic will be required to maintain airspeed during final stages of the approach, especially just prior to landing. A small, gentle reduction in collective after the skids have contacted the ground will assist in maintaining firm contact with the ground and reduce run on length. Right cyclic will need to be introduced after touchdown to maintain heading during the run on. Collective should be lowered judiciously after the aircraft has stopped with downward pressure required on the collective during engine shutdown.

Limitations

3. The following emergency procedure should be used in lieu of that promulgated in Section 3 of Reference F:

HYDRAULICS OUT LIMITATIONS

AUW. Maximum AUW for safe landing in case of hydraulic malfunction is IAW Figure 1.

WARNING

Attempted landing at AUWs above that detailed in Figure 1 in the event of a hydraulics failure may lead to loss of control of the aircraft with catastrophic results highly likely.

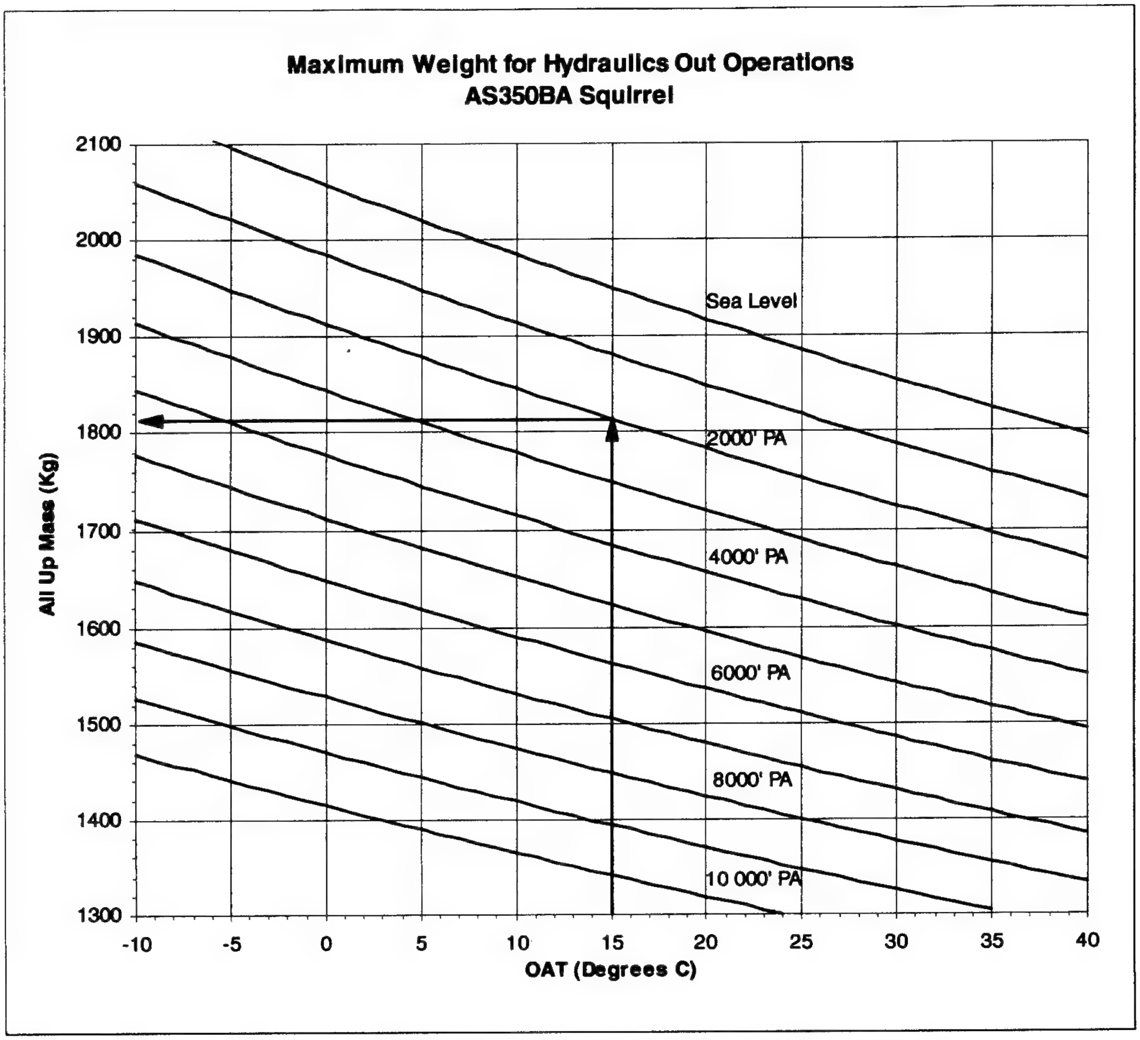
Wind. Landings are only to be made directly into wind. Crosswind or downwind landings are prohibited.

Airspeed. The following airspeed limitations apply to hydraulic OUT operations:

a. Minimum airspeed for touchdown 15 knots through rotor disc. For gusty conditions the minimum airspeed should be increased by half the gust factor.

b. Maximum airspeed is 70 KIAS.

Angle of Bank. The maximum permissible AOB for hydraulic OUT operations is 30°.



Instructions for use: Enter the chart at the OAT (example 15 degrees) and follow vertical gridlines until the desired pressure altitude is reached (example 2000' PA). Follow gridlines across horizontally to read off maximum mass for safe landing hydraulics OUT (example 1815 Kg).

Data basis: Flight Test.

Applicability: Valid for landings into wind with a minimum of 15 knots airspeed through rotor disc at touchdown. In gusty conditions the minimum landing speed should be increased by half the gust factor.

Figure 1

HYDRAULICS OUT TRAINING PROCEDURES

1. The following operational limitations are recommended for practice hydraulic OUT operations to enable effective training and minimise risk:

2. Control forces reduce and control margins increase with reduction in AUW and Density Altitude. For this reason training hydraulic OUT landings should be conducted at lightest AUW for sortie practicable.

3. Airspeed for HYD TEST selection to simulate hydraulic failure may be above 70 KIAS for practice case. The aircraft should be recovered to flight below 70 KIAS and the reversion to ISOL mode made before accumulator pressure is completely depleted from any main servo to avoid differential force gradients in the cyclic control axes.

4. Landings may be made in the ISOL or TEST mode. Aircrew must ensure that prior to landing only one switch is selected to enable rapid reversion to hydraulics ON flight with a single switch selection if required.

5. Reversion to hydraulic ON flight should be pre-briefed before landing and performance limitations set for reversion during landing manoeuvre depending on aircraft captain's experience and ambient conditions (for example reversion to be initiated if heading varies outside of 20 degrees of landing direction or ROD prior to touchdown is in excess of 500 ft/min or pitch attitude is greater than 20 degrees from level). Reversion executive words of command should also be pre-briefed. Thus, should reversion be required for any reason, crewmembers may call "hydraulics, hydraulics, hydraulics" and the non flying pilot restores hydraulic power through TEST or ISOL switch as required. Additionally, a second crewmember will be required to enable the hydraulics to be restored.

6. Intentional reversion to hydraulics OUT flight at Night or in IMC is not permitted.

REFERRED WEIGHT ANALYSIS

1. The following analytical method was used to calculate referred weight for the test program.

$$Referred\ \ Weight = \frac{AUW}{\sigma}\quad [kg] \qquad (1)$$

where

AUW is aircraft All Up Weight in kilograms

σ is the Relative Density

Relative Density

$$\sigma = \frac{\delta}{\theta} \qquad (2)$$

where

δ is the Relative Pressure

θ is the Relative Temperature

$$\delta = \frac{P}{P_0} \qquad (3)$$

where

P is the atmospheric pressure in the area of operation in H_P

P_0 is the ISA atmospheric pressure 1013.25 H_P

$$\theta = \frac{{}^\circ K}{{}^\circ K_0} \qquad (4)$$

where

$^\circ K$ is the surface Outside Air Temperature in Kelvin in the area of operation $(273.15 + T_{OAT})$

$^\circ K_0$ is the ISA atmospheric temperature in Kelvin at sea level $(273.15 + 15^\circ)$

Combining equations (1) to (4):

$$Referred\ Weight\ = \frac{(AUW)(P_0)(273.15 + T_{OAT})}{(P)(273.15 + 15^\circ)}\quad [kg] \qquad (5)$$

2. The following chart can be used to determine referred weight for 1950 kg. Similar charts can be created for other weights if required.

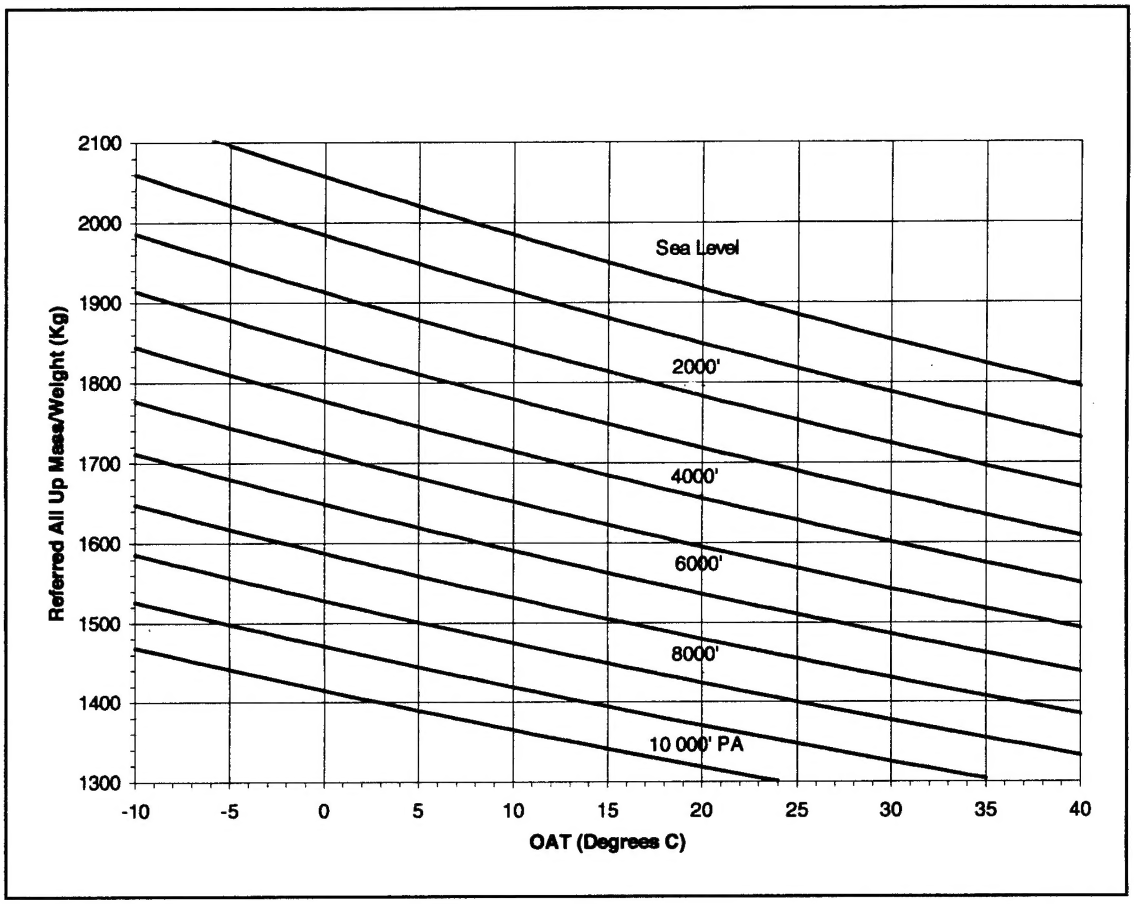


Figure L-1: Referred Weight Conversion Chart for 1950 kg

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DOCUMENT CONTROL DATA

CLASSIFICATION OF DCD PAGES	UNCLASSIFIED
AR NUMBER	AR-009-[illegible] 993
REPORT NUMBER	ARDU-TASK-0301
REPORT DATE	Sep 97
SECURITY CLASSIFICATION **Complete Document** **Title in Isolation** **Summary in Isolation**	 UNCLASSIFIED UNCLASSIFIED UNCLASSIFIED
TITLE	AS350BA SQUIRREL HYDRAULICS OUT EVALUATION
NO OF PAGES	83
AUTHOR	CAPTAIN AJ LANGLEY
CORPORATE AUTHOR AND ADDRESS	AIRCRAFT RESEARCH AND DEVELOPMENT UNIT, RAAF BASE EDINBURGH, SA 5111, AUSTRALIA.
COMPUTER PROGRAMS	MICROSOFT EXCEL™ SigmaPlot™4.0. RSI™
SECONDARY DISTRIBUTION	NO LIMITATIONS
ANNOUNCEMENT LIMITATIONS	NO LIMITATIONS
DESCRIPTORS **Thesaurus Terms** **Non-Thesaurus Terms**	 Helicopters (Eurocopter) Squirrel, Hydraulics
DRDA CAT	010301
ABSTRACT	Task 0301 was an evaluation of the Hydraulics OUT characteristics of the AS350BA Squirrel Helicopter. This report documents the results of that task.